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Number 342

July | August 2016

nitrogen+syngas

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Ammonia Safety Symposium, Denver, Colorado

Iran after sanctions

Feedstock economics

Reformer revamps

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Iran after sanctions

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Reformer revamps

Improving efficiency and boosting capacity.

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BCInsight

More bad news for AN

The terrible gun and bomb attack at Istanbul airport at the end of June has once again highlighted Turkey's ongoing struggle against both Kurdish separatists and Islamic militants, both emboldened by the civil war still raging in neighbouring Syria. But the country's surprise decision to ban the sales of all nitrate-based fertilizers on June 8th was a reaction to a previous series of attacks over the past couple of years, culminating in a car bomb in Ankara in March which killed 35, responsibility for which was claimed by Kurdish group TAK.

> **Turkey is the largest consumer of AN to so far ban its use.**

Turkey joins a growing list of countries which have banned the sale of AN as a fertilizer, including the Philippines, Afghanistan, China and Colombia. Other countries ban the sale of 'pure' AN, such as Pakistan, Germany, Ireland, the UK and Australia, and India has reclassified it as an explosive, severely tightening the regulations on its storage and handling. In almost all cases the concerns were security related. However, Turkey is the largest consumer of AN to so far ban its use, alongside potassium and sodium nitrate. According to IFA figures, Turkey produced 650,000 t/a of ammonium nitrate in 2014, and consumed 1.3 million t/a, making it the 11th largest consumer in the world, and its market was a similar size to major users like the UK and South Africa, with the potential for concomitantly larger upset to the international market.

Ammonium nitrate's misuse by criminals and terrorists is not a new phenomenon. However, the past decade or so has seen this rise to seemingly epidemic proportions, as the improvised explosive device (IED) becomes the weapon of choice of militants in various countries and regions. UK charity Action On Armed Violence has recorded 6,320 IED incidents from 2011-15, responsible for the death or injury of 105,000 people during that time, and amongst these attacks AN-based devices have proliferated, especially in Afghanistan and Pakistan. In Pakistan, as in the UK and Ireland, calcium ammonium nitrate is used in preference to pure AN, but experience with both the IRA and more recently Islamic militants in Pakistan and Afghanistan shows that this merely requires a slightly higher technical knowledge of the bomb maker, but does not prevent its misuse. Turkey meanwhile has calculated that up to 2,500 tonnes of AN fell into the hands of terrorists in the country during 2015, much of it destined to be smuggled across the border into Syria to feed the continuing civil war there. In spite of programmes such as Global Shield, established by the World Customs Organization, Interpol and the United Nations Office on Drugs and Crime (UNODC), and the work of the US Joint IED Defeat Organisation (JIEDDO) – now rebranded as JIDA – the Joint Improvised Threat Defeat Agency, seizures and disruptions to operations continue to be the exception rather than the rule.

AN also faces pressure on other fronts. Earlier this year, the US Chemical Safety Board (CSB) published its final report into the accident at West, Texas in 2012, which killed 15 people. The report highlights various deficiencies in AN storage (wooden bins, lack of smoke alarm/sprinklers), confused and overlapping jurisdictions, and poor zoning regulations. However, it also recommended that fertilizer grade AN storage be treated and regulated as per explosive grade AN. And the US also still awaits the final publishing of the Department of Homeland's Security's (DHS's) regulations on AN misuse, which has been delayed for several years after DHS was instructed in 2007 to set up a program to regulate the purchase of ammonium nitrate. In response DHS has created the Ammonium Nitrate Security Program, requiring purchasers and sellers of AN would to apply for a Registered User Number, allowing them to be screened against the Terrorist Screening Database. The comment period ended in 2011, but according to DHS, those public comments are still being reviewed. The US produces about 4 million t/a of AN, just over half of it explosive grade for the mining industry.

Government and industry have made great strides over the years in trying to make the storage, handling and use of AN safer and to prevent its misuse by criminals and terrorists. However, incidents like West and last year's Tianjin blast in China, and AN's continuing use in IEDs in the Middle East and elsewhere prove that there is still some way to go in terms of enforcement of existing regulation, and with the consequences so potentially devastating, more governments may end up taking the path that Turkey has done, and erring on the side of caution. ■

Richard Hands, Editor

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Price trends

MARKET INSIGHT

Laura Cross, Senior Analyst, Integer Research, assesses price trends and the market outlook for nitrogen.

NITROGEN

Abundant supply and weak prices have created some of the most difficult fertilizer market conditions seen in a decade. The nitrogen market however, is not feeling as much of the brunt of financial losses seen in previous market downturns. Nitrogen producers at the high-cost end of the industry cost curve in particular have found themselves better equipped to withstand the tumbling nitrogen prices experienced in 2015 and 2016 so far as a result of the fundamental shift in energy pricing that has occurred in the last 18 months.

Decreasing feedstock costs to nitrogen producers have mitigated the extent to which producers are feeling the strain of current cyclical weakness in the market, and contrary to other fertilizer nutrients, investment in nitrogen capacity continues, although there are signs of slowing as the gap between international nitrogen prices and the incentive price to build new capacity widens.

In light of the overhaul in global energy costs, the competitive makeup of the nitrogen industry has now fundamentally changed. A key development is that the range in production costs is now far smaller than it was in previous years, and this makes it more difficult to determine the location of the industry margin.

Another key development is the decreasing profitability of urea relative to other nitrogen products such as ammonia, nitrates and UAN. The effect of global nitrogen oversupply has been most critical in the urea market which has driven tumbling prices, much more so than in other product markets where supply growth is less rapid and consumption is more regional. Therefore the focus for producers that are involved in more than one product market is to maximise returns from niche nitrogen markets where margins are somewhat shielded from the commodity cycle and where higher unit returns can be achieved. Similarly there has been growing interest from urea-focussed producers looking to diversify their product mix by entering downstream or value-add markets in order to reap the rewards that can be achieved over urea in today's market.

This trend is most obvious when we consider the unit margins of producers with a broad nitrogen product mix, such as CF Industries and Yara. CF Industries' AN gross profit margin increased by 26% year-on-year in 2014 to $571/tonne despite the AN NOLA price remaining relatively stable over this period. By comparison, CF Industries' urea margin fell by 26% year-on-year to $344/tonne in 2014. Yara's AN gross profit margin from its Sluiskil, Netherlands plant also increased by 13% year-on-year to $472/tonne in 2014.

The global gross margin curve which measures competitiveness of producers per tonne of nitrogen product allows us to identify standout regional clusters across all nitrogen products. It shows that UAN producers in North America remain highly competitive as a result of low costs due to falling natural gas prices, benefiting from a significant local price premium driven by import parity pricing in the US. The US dominates the UAN market, both in terms of production and consumption, and despite weak global prices, there is still investment rationale in key pockets of regional consumption. The main drivers behind continued capacity additions in the US are low gas costs as a result of the recent shale gas revolution, coupled with a domestic price premium over international levels as a result of continued import dependence. US imports of urea increased by 68% or 3.2 million tonnes between 2004 and 2014 to meet consumption in the face of capacity closures at the time when North America was operating as the industry swing producer. Similarly, UAN imports increased by 52% over the same period.

Of the current planned greenfield projects in the US, the IFCo/OCI project in Lee County, IA, is the most advanced and due for completion in Q4 2016. The urea integrated facility has a urea capacity of 765,000 tonnes per year, most of which will be used for UAN at a capacity of 1.5 million tonnes per year. CF Industries' new plant in Port Neal, IA will also add 770,000 tonnes per year of UAN capacity when the plant begins commercial production in 2017. There is also a significant stream of new ammonia capacity additions, which are due to come online in the next 18 months. The projects by Dyno Nobel at Waggaman, LA, Yara/BASF in Freeport, TX and JR Simplot in Rock Springs, WY, will add a combined ammonia capacity of 1.7 million tonnes by the end of 2018. This additional capacity will displace some US imports in the near future, and require producers to reallocate US import volumes. These developments will have profound implications for the US nitrogen market and beyond, from substitution trends between nitrogen products and the balance between growth rates for fertilizer and industrial markets, to quantifying opportunistic exports from the US Gulf and where we can expect traditional exporters to the US to redirect their export volumes to as the country's import dependency shrinks in the coming years. ■

Table 1: **Price indications**

Cash equivalent	**mid-May**	**mid-Mar**	**mid-Jan**	**mid-Nov**
Ammonia ($/t)				
f.o.b. Caribbean	280	270	270	360
f.o.b. Arab Gulf	335	320-340	308-323	390-425
c.fr N.W. Europe	358	325-355	348	410-445
c.fr India	383	340-388	368	440-470
Urea ($/t)				
f.o.b. bulk Black Sea	201	200-204	220	258-263
f.o.b. bulk Arab Gulf*	190-199	230-265	201-211	255-263
f.o.b. bulk Caribbean (granular)	215	210-220	221	250-255
f.o.b. bagged China	209	200-205	222	252-255
DAP ($/t)				
f.o.b. bulk US Gulf	345	360	395	410
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	138	175-180	175	183-186

Notes: n.a. price not available at time of going to press
*n.m. no market   * high-end granular*

Source: Fertilizer Week

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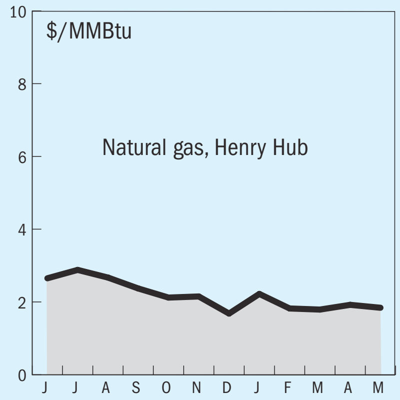
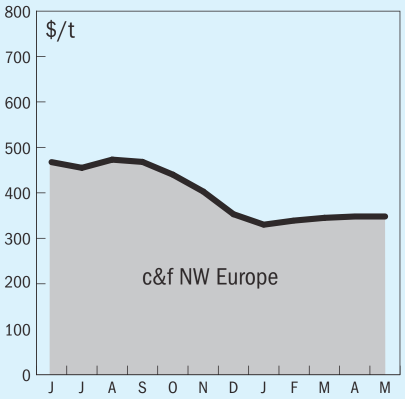
END OF MONTH SPOT PRICES

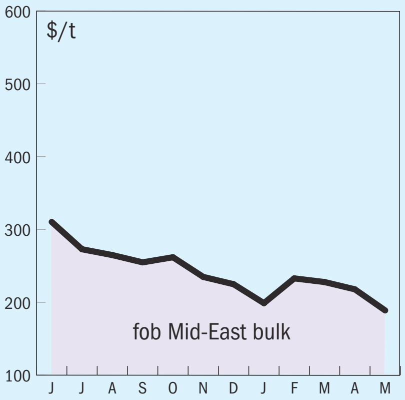
natural gas



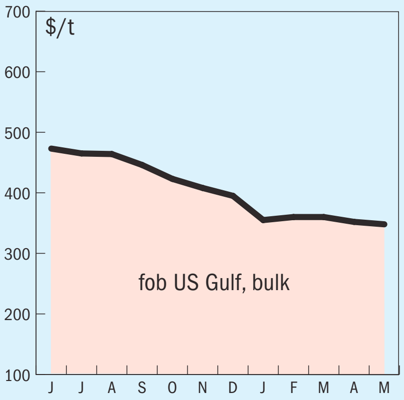
ammonia



urea



diammonium phosphate



MARKET INSIGHT

Mike Nash, Global Business Director, IHS Chemical, assesses the market for methanol.

METHANOL

In the US, the June contract natural gas reference price was settled at $2.51/MMBtu for Texas, and $2.04/MMBtu for Louisiana, with Texas up $0.65/MMBtu from May. We are seeing typical, slower summer activity in the spot market, with a number of participants out on vacation. Demand overall is good at a seasonal peak. Price ideas for July are slightly lower than we saw in the second half of June with some of the supply constraints beginning to pass. Methanol demand remains steady overall, but MMA production has experienced some production constraints due to limited feedstock from the acetone side. Production across the Americas is operating at an average of 88%. In South America, Venezuelan units are believed to be running at around 70% of nameplate capacity, but the country is still struggling to maintain civil order that could potentially disrupt operations. Methanex's Chilean unit is operating at 50% of nameplate capacity and Trinidad is back up to 80%. The spot market has been thin with July ideas ranging from $0.62 – 0.66/gal. IHS Chemical posts the US spot price for July notionally in a range of $218-219/tonne f.o.b. Houston basis. Official posted reference prices from the major producers for July are $0.80/gal for Methanex (a rollover from last month) and $0.81/gal for Southern Chemical.

In May 2016, legislation was introduced to Congress to extend the biodiesel tax incentive through 2019 and restate it as a domestic production credit versus the blender credit it currently is.

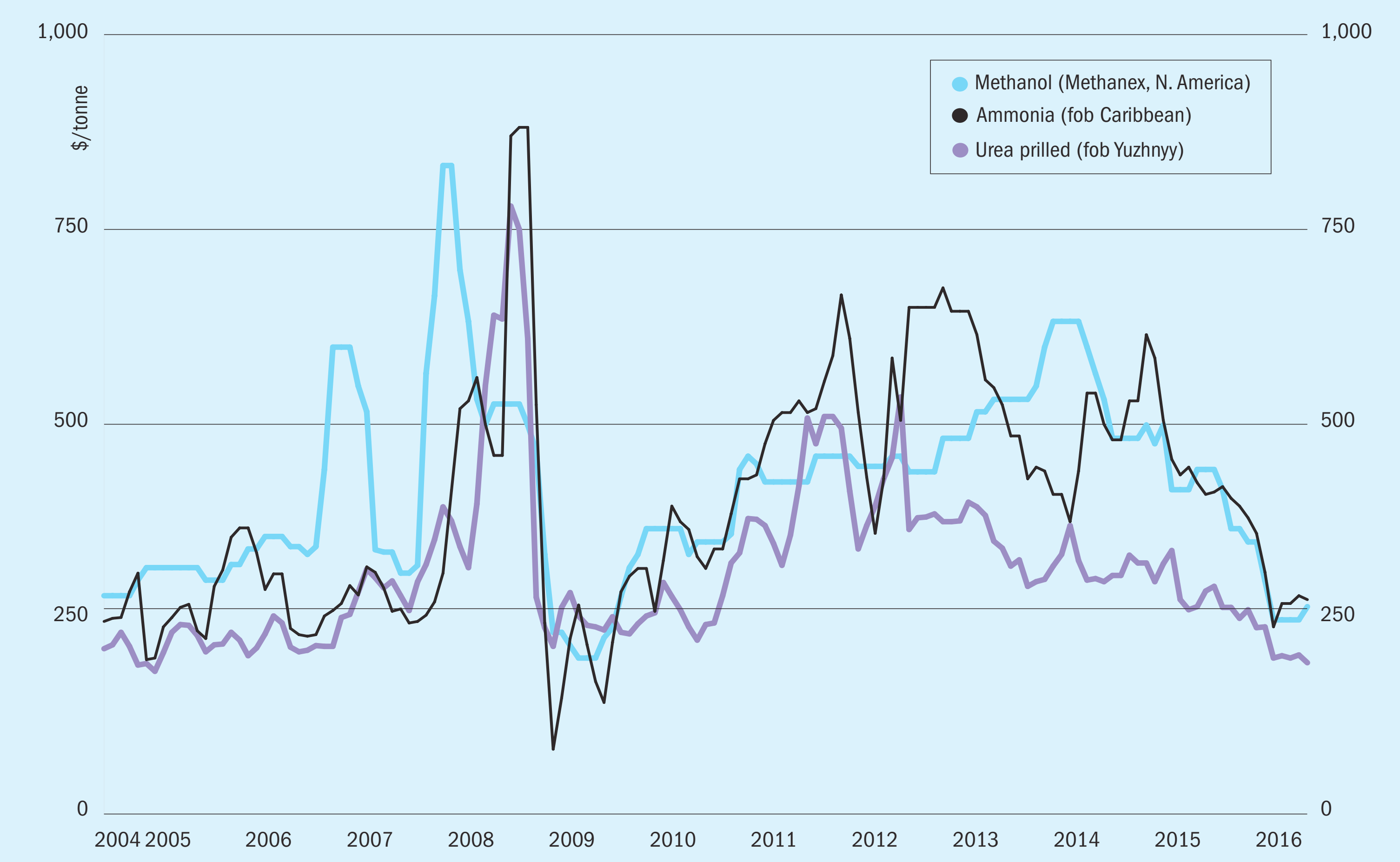
In China, the methanol market quickly recovered after a post-Brexit dip. The methanol futures market price picked up and the spot price spread between buyer and sellers widened as sellers quickly increased their selling indications. Currency inflation and major players' speculation in the futures market are the main reasons for the increase in methanol futures prices. China's industrial profit growth continued to soften in May; the pace was much slower compared with April. According to the National Bureau of Statistics (NBS), year-to-date profit growth fell to 6.4% from 6.5% through April, and cumulative growth declined by 0.5 percentage point from the previous month to 3.7%.

Chinese domestic methanol production is stable. The average operating rate remains at around 52% of nameplate capacity, or close to 66% of effective capacity. MTO producers continued to build up inventory levels through significant volumes of contract shipments, and are not under urgent pressure to buy spot methanol unless the price is below the buyers' expectations. Demand into the MTO sector remains robust. Most of the major MTO units are operating at maximum rates; MTO economics are supported by the current strong ethylene price as well as relatively advantageous prices for downstream products such as polyethylene and polypropylene. Demand into formaldehyde and MTBE is stable. Demand into acetic acid declined slightly. For import material, selling indications have increased to $230-238/tonne. A deal for non-Iranian cargo was concluded at $225/tonne for July loading, while a deal for Iranian cargo was concluded at a price around $220/tonne. Methanex posted its Asia Posted Contract Price (APCP) at $275/t for July 2016, a rollover of June's price.

In Korea, the market is very stable and quiet with little product movement. Selling indications from international traders remain in a range of $240-245/t, where they have consistently been for the last few weeks. IHS Chemical posts the weekly price in a range of $235-240 per metric ton c.fr. In Taiwan, end-users are adequately supplied by term contracts, and are currently benefiting from a healthy inventory level. The c.fr Taiwan price is in a range of $220 -230/t. In Southeast Asia, all major units are running to plan to meet regional demand. Spot buying sentiment is low with some non-urgent buying interest from end-users. In Thailand, the government is developing a new policy to encourage the usage of biodiesel. The energy ministry has agreed to subsidize the use of B20 in trucks under a trial program that will pay companies $0.11/litre of biodiesel consumed for up to 50,000 litres. The government will also study the use of B10 in military and government fleets. Currently the country produces 4.2 million litres/day of biodiesel, but with B10 and B20 implemented, consumption would increase to more than 10 million litres/day. ■

Market outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- Global ammonia demand was set to soften in June keeping downward pressure on prices, and capacity ramp ups in the US and Russia are set to increase global availability going into Q3 2016.
- However, new capacity coming online is expected to be offset by reduced supply from Trinidad where increased feedstock curtailments have led to lower inventories.
- While weak ammonia demand in the Asia-Pacific region is expected to push ammonia prices downwards over the summer months, demand in Asia, especially from India, may provide some support to Yuzhny and Middle East FOB prices.
- The outlook for energy prices suggests that continued low natural gas prices in Europe and North America in the short term is likely to keep producer margins healthy in spite of prevailing low nitrogen prices.

UREA

- Urea price sentiment continues to be weak across most regions globally in light of continued oversupply and a seasonal lull in demand.
- Chinese sellers are expected to shift their focus to exports in July as the domestic season comes to an end.
- Egyptian producers were running plants at 65% of capacity at press time due to gas supply curtailments amid the country's ongoing shortage of natural gas.
- Several US capacity expansions due to come online in Q3 2016 could displace some imports in the near future, although the country will remain a net importer, especially for urea, for many years to come.
- It is possible that the start-up of several new VAN plants in the US could lead to substitution.
- Other urea importing regions, such as Brazil, have seen recent business at lower price levels in early July, driven by the prevailing market oversupply.

METHANOL

- The methanol market appears to be relatively stable. Robust demand is being balanced by ample supply.
- In spite of industrial demand in China continuing to slow, demand from petrochemical end uses like ethylene and propylene is being kept up by advantageous prices and MTO demand continues to be robust.
- Markets are still finding a level after the impact of Britain's 'Brexit' vote on currency markets.
- Both the US and Thailand are looking towards greater demand from bioldiesel in the longer term.
- Venezuela's continuing social problems pose a potential threat to disrupt methanol capacity and exports there in the medium term.
- Gas curtailments in Trinidad are expected to end in 2017 with the start-up of new gas fields. BP has announced the startup of its Sercan and Juniper gas fields with 275 million scf/d at that date. ■

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Nitrogen Industry News

TURKEY

Turkey bans sale of ammonium nitrate

Turkey has suspended all domestic production and sales of ammonium nitrate fertilizer, as well as other nitrate-based fertilizers including CAN, potassium and sodium nitrate. The move is a response to its use in a series of terrorist bombings which have targeted police and security forces in the country, most recently on June 7th, when a car bomb exploded in Istanbul. In a press release, Turkish Agriculture Minister Faruk Celik said: “Turkey has banned the sale of fertilizers which could be used as explosives, so all sales of the fertilizer nitrate can no longer be carried out in Turkey.”

Previous security measures in relation to ammonium nitrate in Turkey have included a ban on sales of any fertilizer with more than 28% N content coming from nitrate and the placement of tracking chips in random bags, but this has failed to prevent a series of bombings blamed in the Kurdistan Workers Party (PKK) using AN-based improvised explosive devices.

Turkey uses 5.5 million t/a of fertilizer, of which 1.5 million t/a is ammonium nitrate-based, according to the Agriculture Ministry. CRU puts Turkish imports of fertilizer-grade ammonium nitrate at 625,000 t/a in 2014, with domestic production at 306,000 t/a. CAN production in Turkey in 2014 was 722,000 t/a. All pending sales, amounting to 64,000 tonnes, have been stopped. ■

UNITED STATES

IGCC plant bought for ammonia production

Philipp Brothers (‘Phibro’) says that it has incorporated a new company, Philipp Brothers Fertilizer, together with a group of investors – the Phibro Group – and that they have acquired a coal gasification plant from SG Solutions at West Terre Haute, Indiana, which they intend to convert to produce 500,000 t/a of ammonia. The coal gasification plant formerly produced syngas as part of the Wabash River Combined Cycle Plant owned by Wabash Valley Power Association. One train of the coal-fired power plant was converted to coal gasification in 1995 in the “clean coal” era. The other five trains were all retired earlier this year, casualties of low natural gas prices and increasing restrictions on emissions, and Wabash Valley says that it is instead moving “aggressively” towards renewable-based power generation.

The conversion and addition of an ammonia ‘back end’ to the plant will cost $450 million, and Phibro says that it is targeting a mid-2018 completion date. Instead of coal, the plant will run on petroleum coke sourced from local refineries. Phibro says that it can achieve a feedstock cost of as little as $0.50/MMBtu that way, giving it a margin even over cheap shale gas-based ammonia plants. The plant would be only the second petcoke-based nitrogen facility in the US, joining the CVR Coffeyville fertilizer plant in Kansas, which uses petcoke from the neighbouring Coffeyville refinery.

Simon Greenshields, president and CEO of Phibro LLC, said; “We are thrilled to be able to put this plant’s technology, which has outlived its viability in an era of reduced coal-fired power generation, to a more productive economic use, manufacturing much needed ammonia fertilizer for the region. This transaction benefits numerous stakeholder groups as it will create and save manufacturing jobs, provide the most affordable fertilizer for farmers in the area and reduce our nation’s reliance on imported ammonia fertilizer.”

Arkansas ammonia plant up and running

LSB Industries, Inc. says that its new 375,000 t/a ammonia plant at its El Dorado, Arkansas facility became operational during May and that it expected to be selling ammonia into the adjacent pipeline by the end of the month. The plant will gradually ramp up production over the subsequent two months and is expected to reach full capacity by the beginning of the third quarter of 2016. LSB puts the total cost of the project at approximately $830 million, including the ammonia plant and the construction of a new nitric acid plant and concentrator which were completed in 2015.

“We are pleased to have achieved this critical milestone with the start-up of the new ammonia plant at our El Dorado Facility,” stated Daniel Greenwell, LSB’s Chief Executive Officer. “We believe that the ammonia plant will significantly enhance the financial performance of the El Dorado Facility and have a materially positive impact on LSB’s overall performance. We look forward to sharing these results with our shareholders in the upcoming quarters.”

Cronus nitrogen plant delayed

Construction on a massive nitrogen plant in eastern Illinois could be delayed until next year, according to local press reports. Developer Cronus Chemicals, owned by a group of Swiss and Turkish investors, originally planned to begin construction at the site near Tuscola in 2015, but local officials indicate that while road improvement and some site preparation may begin this summer, actual construction work on the project may not start until 2017. Cronus cites “ongoing negotiations with contractors” as one of the sources of the delay; Maire Tecnimont is in charge of the EPC contract, with KBR Inc as a key licensor. Meanwhile the estimated cost of the project has risen from $1.4 billion to $1.9 billion, although Cronus says this is because of financing costs, not construction costs. The facility will produce 800,000 t/a of ammonia and 1.4 million t/a of urea when complete. The US Environmental Protection Agency has granted the company a one-year extension on its air emissions permit; construction now must start by October 2017.

GERMANY

Clariant catalyst partnership inaugurates new research centre

The Technical University of Munich (TUM) has inaugurated a new building for its Catalysis Research Centre (CRC), which will be home to MuniCat, the catalysis research alliance between Clariant and TUM. According to Clariant, MuniCat follows an “industry on campus” approach: TUM scientists and Clariant researchers work together to resolve questions of fundamental and applied research in chemical catalysis. Since its inception in 2010, more than 50 PhD, Masters and bachelors students have worked on ten successful MuniCat research projects.

Comprising more than 75 state-of-the-art chemistry and physics laboratories, the venue is designed to facilitate collaboration among the 19 CRC research teams, which represent complementary aspects of catalyst studies, from theory

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and development to technological application. The facility is one of the largest research centres at TUM.

Stefan Heuser, senior vice president and general manager of the Business Unit Catalysts at Clariant, stated: "MuniCat, Clariant's strategic partnership with the Technical University of Munich, plays a vital role in our technical catalysis research. We look forward to further joint scientific successes in the new Catalysis Research Centre."

BRAZIL

Yara considers purchase of Vale fertilizers

Although denied in April, Yara confirmed in May that it is considering purchasing part of Vale's fertilizer business in Brazil, which is now the world's fourth largest consumer of fertilizers after China, India and the US. Vale is reportedly looking to sell a 40% stake in its Brazilian fertilizer assets for around $1.2 billion as part of a plan to raise $10 billion, after posting its largest quarterly loss in decade. The company's fertilizer assets include Fosfertil – Yara's share of which Vale bought out in 2010. Yara subsequently bought Bunge Fertilizers from Vale in December 2012.

INDIA

Urea prices to be frozen

The Indian government says that it will freeze urea prices at their present levels for the next three years, according to Fertilizer Minister Hansraj Gangaram Ahir. The move comes at the same time that the government is piloting the transfer of fertilizer subsidies directly to farmers rather than via urea producers. The so-capped direct benefit transfer (DBT) scheme is already in use for health insurance, and the government is now extending this to farm subsidies in select areas, to check that the system works. The government will also issue farmers with a credit card to allow them to afford up-front payments for fertilizer. It hopes to double farm incomes by 2022, via increased rural spending, crop insurance, irrigation, protecting soil health and connecting farms to markets, as well as the more balanced use of fertilizers.

The government has also encouraged the use of coated urea, using neem, made from plant oil. This reduces leaching and slows release of urea, making it more efficient and meaning that farmers require less of it, as well as making it cheaper. Currently domestic producers must produce 75% of their output as neem-coated, up from 35%, but they can coat up to 100% of output. The government says that this has reduced demand for urea at the same time that it is encouraging higher production.

IRAN

Partner selected for Indian urea development

The Indian fertilizer companies involved in developing an Indo-Iranian joint venture ammonia-urea plant in Iran have shortlisted the privately owned Pasargad Energy Development Company (PEDC), a subsidiary of Iran's Bank Pasargad, as their Iranian partner. PEDC owns land in the Chahbahar region on the border with Pakistan, where the plant is likely to be sited as part of a large joint venture development between India and Iran involving aluminium and a port facility. India will be spending around $500 million to develop the port in Iran's south-eastern province of Sistan-Balochistan as a regional trade hub. The three Indian companies involved in the fertilizer plant are Rashtriya Chemicals and Fertilizers (RCF), Gujarat Narmada Fertilizers and Chemcials (GNFC) and Gujarat Chemicals and Fertilizers (GSFC), and the aim is to build a 1.3 million t/a ammonia-urea plant based on cheap Iranian gas with the urea being exported to the Indian market.

UKRAINE

OPZ to be privatised

The Odessa Port Plant (OPZ) is set to be privatised after Ukrainian authorities reached agreement over the ammonia producer's fate. The cabinet approved the sale of 99.6% of the plant's shares at a meeting on May 18th, according to the government, with the starting price for the stake to be $521 million. Agreement was reached following an amendment to the country's privatisation law in February which banned Russian companies from being able to buy stakes in Ukrainian state owned entities. The sale will be the first privatisation since the 2013 uprising that ousted the previous president, and the third largest in the country's history. Sale of the plant has been the subject of a long-running legal wrangle, with Nortima, which tried to buy the plant in 2009, still claiming that its right to buy stands. Nortima has been linked to the Privat Group, run by oligarch Ihor Kolomoisky. The plant is also in debt to both the Ukrainian government and the Ostchem Group, run by gas trade multi-millionaire Dmytro Firtash, who has supplied gas to the plant, and who is reportedly owed $193 million by OPZ. Firtash currently runs most of Ukraine's private fertilizer industry via his Group DF.

TANZANIA

Construction on urea plant to begin this year

Tanzania said on Friday it plans to start building a $3 billion fertiliser factory in partnership with a consortium of investors from Germany, Denmark and Pakistan this year. Officials said the state-run Tanzania Petroleum Development Corporation (TPDC) has signed a joint venture agreement with German engineering firm Ferrostaal Industrial Projects, Haldor Topsoe and Pakistan's Fauji Fertilizer Company to develop the plant, which will produce 3,800 t/d of urea. Output will be aiming at the domestic as well as international market. Agriculture contributes more than a quarter of Tanzania's gross domestic product (GDP) and employs around 75% of the labour force, but growth is stifled by low crop yields, and the country currently imports most of its fertiliser.

The plant will built in southern Tanzania near large offshore gas finds. Tanzania announced in February that another 2.2 trillion cubic feet of gas had been discovered onshore, raising the country's reserves to more than 57 tcf. The start-up date for the new ammonia-urea complex is currently put at 2020.

PAKISTAN

Budget includes major package for agriculture

Agriculture represents 21% of Pakistan's GDP and 44% of its employment, but has seen declining farm incomes in recent years due to lower commodity prices and poor weather. For its 2016/17 budget, therefore, prime minister Nawaz Sharif's government has announced a package of measures to try and boost agricultural productivity and incomes, including subsidies on urea and DAP sales, direct cash support, and concessionary electricity tariffs for agriculture. Urea prices will

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fall from 1,850 rupees per bag to 1,400, having previously been reduced from 2,050 rupees.

FRANCE

Borealis buys AN storage site

Borealis LAT France and Eliard-SPCP announced that they have signed an agreement for the purchase by Borealis of Eliard's ammonium nitrate storage site at Luitré. This site has permission to store up to 4,900 tonnes of ammonium nitrate. Eliard-SPCP is moving its seeds and fertilizer activities to a site 500m away – in order to meet strong growth in demand for its "forage seed", Eliard-SPCP is investing in two new storage warehouses at Luitré (completed in July 2016) and Pontivy. The company is also developing a new range of blended fertilizers using the latest technologies in the port of Nantes. Borealis says that this acquisition increases its storage capacity in France and reaffirms its growth strategy, with the objective of developing its fertilizers business by strengthening its sales and logistics capabilities.

INDONESIA

Financial closure for ammonia project

Mayer Brown JSM, the international legal advisor to the International Finance Corporation (IFC) on its investment in a $830 million greenfield ammonia plant in Sulawesi, Indonesia, says that the project has now achieved financial closure. The plant, being developed by Panca Amara Utama (PAU), is one of the IFC's largest greenfield projects in the last decade. It is funded through a $512 million debt package consisting of a $97 million IFC A loan and a $415 million IFC B loan funded by ANZ, HSBC, Korea Development Bank, OCBC, Standard Chartered Bank, SMBC and United Overseas Bank. The IFC is also taking an equity position in PAU in the form of a convertible loan.

Ground was broken in August last year on the 660,000 t/a ammonia facility. Toyo Engineering is the EPC contractor, licensing technology from KBR.

ISRAEL

New ammonia plant ready for tender

Israel's Environmental Protection Ministry has given a timetable for the proposed new ammonia plant which is to be constructed at Mishor Rotem, in the southern desert between Dimona and the Dead Sea. Speaking at a press conference, EPM director-general Yisrael Danczinger said that the EPC contract is currently out for tender, with bids closing at the end of August and a licensor and engineering, procurement and construction contractor being chosen. Construction is expected to begin in late 2016 or early 2017, and take three years to complete, with an on-stream date projected for 2020. The capacity for the new plant has not been specified, but it is being constructed in order to retire the 17,000 tonne ammonia storage tank at Haifa which is presently used to import ammonia for Israel's chemical and fertilizer industry, the presence of which has been a longstanding bone of contention with Haifa residents, especially when Hezbollah secretary general Hasan Nasrallah threatened recently to target the tank with rockets and poison the city of Haifa. Israel's demand for ammonia is around 120,000 t/a, and the new ammonia plant is likely to be of around that size.

However, there have reportedly been questions from contractors as to the financial viability of the project, which had led the government to delay the tender in order to improve its financial terms. Particularly under scrutiny from potential investors is the price for natural gas feedstock. The Mishor Rotem site, in the Negev desert, is home to power and other facilities, including one of the sites owned by Haifa Chemicals, the main consumer of ammonia in Israel, as well as nearby phosphate mining activities. It is also home to Israel's uranium processing activities for the Dimona nuclear reactor. ■

CORRECTIONS

Uhde Fertilizer Technologies (UFT) has asked us to correct a figure which they gave in last issue's article on sulphur enhanced urea (*Nitrogen+Syngas* 341, May-Jun 2016, pp32-39). The number given for sulphur concentration in the second line of Table 1 on page 34 is incorrect. Instead of 0.36%, it should read <0.1%.

UFT has also asked us to clarify that in the Nitrogen Project Listing in our March/April issue (*Nitrogen+Syngas* 340, p31), for the Midwest Fertilizer Company facility in Indiana, USA, while Stamicarbon are the licensor for the urea melt plant, as shown, the urea granulation plant will be licensed by UFT.

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Syngas News

UNITED STATES

Yuhuang pressing ahead with methanol project

Yuhuang Chemical says that it expects to break ground in 4Q 2016 on its $1.85 billion methanol project in St. James Parish, Louisiana. According to a vice president of Manufacturing Operations Jerry Oliver, speaking at the Petrochemical Engineering & Construction conference in June, the front-end engineering and design work, being conducted by Amec Foster Wheeler, is complete, and detailed engineering is about 30% complete. Plant construction is expected to be complete and methanol in production by early 2019. The plant will have a capacity of 5,000 t/d (1.7 million t/a). The company says that it is also still planning to add a second train of a similar size, with construction beginning in 2019, as well as downstream derivative capacity. The company will license Lurgi *MegaMethanol* methanol technology from Air Liquide, who will also provide the air separation units to generate oxygen for the autothermal reforming process.

Longer term, the company is looking towards potential third and fourth methanol trains out to 2026, taking capacity to 20,000 t/d. Oliver said that Yuhuang, owned by Chinese chemical producer Shandong Yuhuang Chemical Group, aims "to become a major player in the [US] market" and that it was undeterred by the plethora of other methanol projects under development in North America. Another 5 million t/a of methanol capacity is due to come on-stream by 2020 in Louisiana alone. Yuhuang says that the plant's output is likely to be split 50% for domestic use and 50% for export. ■

Celanese considering second methanol plant

Celanese says that it is continuing to work on developing a second methanol plant in the US with partner Mitsui & Co, according to ICIS. The partners' first joint venture methanol plant, at Clear Lake, Texas, came on-stream in October 2015, with a capacity of 1.4 million t/a. The projected on-stream date for the new plant would be 2019-2020. While it may not be a final investment decision, the company believes that there will be greater clarity on whether to proceed with the project by the end of 2016.

Tecnimont and Siluria to develop gas-based ethylene technology

Maire Tecnimont and SiluriaTechnologies have signed a joint collaboration agreement agreeing to combine their respective technologies and expertise in order to bring to market a unique process to convert natural gas directly into ethylene and downstream products. Siluria's catalyst and process technologies uniquely combine nanomaterials, catalyst development, and chemical engineering, and the Oxidative Coupling of Methane (OCM) process, developed by Siluria, allows the direct conversion of natural gas to ethylene. It hopes this might be the basis of small-scale on-purpose and distributed scale ethylene production. The company also has a second process which can convert ethylene to liquid fuels such as gasoline.

"This collaboration capitalizes on Maire Tecnimont's international competencies in engineering and construction, technology licensing and new business development," said Pierroberto Folgiero, Maire Tecnimont's chief executive officer. "We are eager to combine these core strengths with Siluria's ground-breaking technology development platform to offer a unique, high-value solution to petrochemical customers."

"We are excited to expand our product portfolio by teaming with Maire Tecnimont, to enable a completely new pathway to produce additional petrochemical derivatives from natural gas," said Erik Scher, Siluria's interim CEO and president. "This new product offering will expand Siluria's portfolio beyond our current solutions focused on gasoline and ethylene, to address an even larger share of the global petrochemical and energy market."

Linc files for Chapter 11 in US

Underground coal gasification (UCG) developer Linc Energy has filed for Chapter 11 bankruptcy protection in the US. The company had been planning to conduct commercial UCG production in Wyoming's coal-rich Powder River Basin, but low US natural gas prices have eroded any commercial advantage to be found from using coal to generate syngas. It began to try and minimise capital expenditure in 2014 by selecting well reworks, well recompletions and new well drilling based on a rigorous economic analysis, according to its filing with the US Bankruptcy Court in Texas, but currently finds itself with assets of $50-100 million and liabilities of between $100-500 million.

DENMARK

Topsoe publishes research in improved methanol catalysts

A research team from Topsoe and the Technical University of Denmark has established a unique molecular-level understanding that enables scientists to 'tune' methanol catalysts at the nano-scale, resulting in record performance. The article, published in leading scientific journal *Science*, shows how optimised use of zinc oxide can make industrial methanol catalysts produce significantly more methanol without consuming more energy. This means that the world's growing demand for methanol can be produced using fewer resources and raw materials in the near future.

"The news is that we have shown how to optimally control the well-known promoter zinc oxide. To understand in detail how zinc oxide boosts the effect of the copper-based methanol catalyst was a challenging task because the catalyst is extremely dynamic and the process takes place at nano-scale and at high temperatures. But we combined a variety of methods in our experiments to show how the size and placement of the zinc oxide nanoparticles on the surface of the catalyst has a significant influence on how efficiently the catalyst produces methanol," says Jens Sehested, senior scientist, Haldor Topsoe R&D.

UNITED KINGDOM

Global methanol capacity to reach 184 million t/a

Global methanol capacity is set to grow from 117.5 million t/a in 2015 to 184.4 million t/a by 2020, according to research and consulting firm GlobalData. The company's latest report says that 49 planned projects are due to come on-stream over the next five years, primarily in China and Iran, where there are 17 and 12 projects respectively. China's methanol capital expenditure will total an estimated US$13.4 billion over the next five years, far higher than the next highest spender – the US – at US$6.44 billion. China Petroleum & Chemical Corp and Shenhua Group are among the top companies by capacity addition globally, with 4.1 million t/a and 3.3 million t/a, respectively, expected to come on-stream over the next five years.

In Iran, Kaveh Methanol Co. accounts for most capacity addition, but the leading company for methanol capacity additions to 2020 will be GigaMethanol BV, based in Mozambique, and projected to add 5.3 million t/a during the forecast period.

CHINA

Honeywell breaks ground on MTO catalyst plant

Honeywell UOP says that it has broken ground on a new facility outside Shanghai to produce catalysts for the conversion of methanol from coal into petrochemical feedstocks for plastics. When it enters production in 2017, the catalyst production line in Zhangjiagang City in Jiangsu Province will produce state-of-the-art catalysts used in Honeywell UOP's advanced methanol-to-olefins (MTO) process technology.

"MTO is an innovative, proven technology that enables countries such as China that are rich in coal, but which have had to import petroleum, to make plastics," said Rajeev Gautam, president and CEO of Honeywell's Performance Materials and Technologies business group. "Honeywell UOP has licensed eight MTO units in China in just the last three years, and this new facility will allow us for the first time to fully manufacture MTO catalysts in China for our Chinese customers."

In 2011, Wison Clean Energy Company became the first company to license the Honeywell UOP MTO process, which entered commercial production in 2013. Since that time, seven other companies concluded MTO licensing agreements with Honeywell UOP. The most recent of these was Luxi Chemical Group last December. While global demand for ethylene and propylene is growing by 4% to 5% per year, China is expected to invest more than $100 billion in coal-to-chemicals technology by 2020. This would reduce China's dependence on imported oil for the manufacture of plastic resins, films and fibres that are used to make millions of different products.

"The Zhangjiagang facility makes it possible for Chinese manufacturers to meet the growing demand for petrochemicals with Honeywell UOP technology," said Rebecca Liebert, president and CEO of Honeywell UOP.

GERMANY

CO_2 to chemicals project

Speciality chemicals manufacturer Clariant has announced its participation in the Carbon2Chem project, a cross-industry initiative for the reduction of industrial CO_2 emissions from steel facilities. The project is now entering its active phase, which will be sponsored by the German Federal Ministry of Education and Research for an initial period of four years.

The project aims at transforming smelting gases from the steel industry into value-added downstream chemicals. Currently, these chemicals are only used energetically – as a source of power generation in the steel power plant. The objective of the Carbon2Chem project is to find a solution for using the smelting gases for the production of useful materials, for example methanol. Clariant will provide methanol catalysts and the necessary application know-how in order to validate their suitability. The company will also participate in the upstream processing of the smelting gases. For the gas purification, Clariant contributes adsorbents, catalysts and expert know-how on their application. To sustainably improve the ecological performance of steel production, Clariant considers it an important step to convert components of the smelting gases, which also contain considerable amounts of hydrogen.

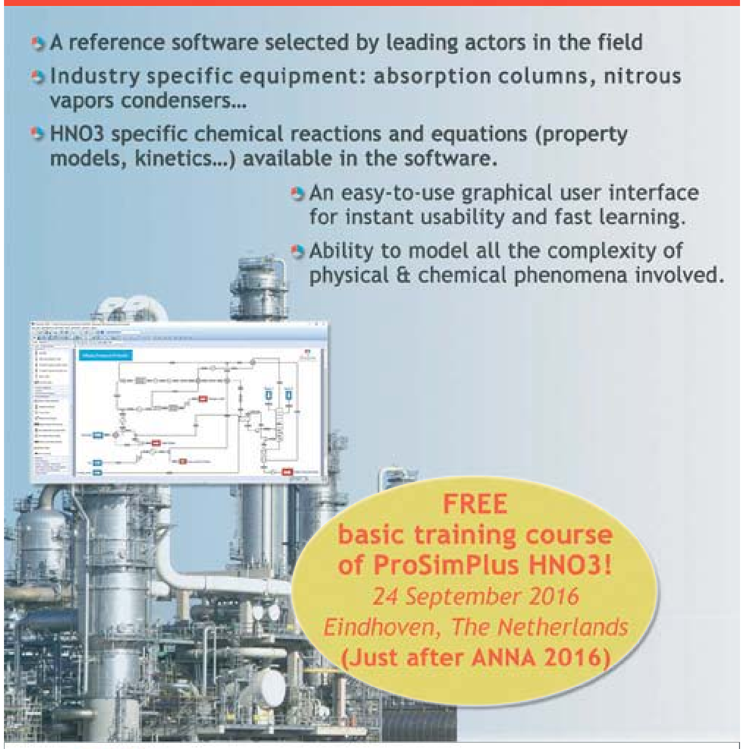
EUROPE

EMSA positive on methanol as shipping fuel

The European Maritime Safety Agency (EMSA) has issued a report on methanol and ethanol, saying they are good potential alternatives for reducing both the emissions and carbon footprint of ship operations. As they are sulphur-free, use of methanol and ethanol fuels would ensure compliance with the European Commission Sulphur Directive.

Investment costs for both methanol and ethanol retrofit and new build solutions are estimated to be in the same range as costs for installing exhaust gas after treatment (scrubber and selective catalytic reduction) for use with heavy fuel oil, and below the costs of investments for LNG solutions. A payback time analysis carried out for the study indicated that methanol is competitive with other fuels and emissions compliance strategies, but this depends on fuel price differentials. Based on historic price differentials, methanol will have shorter payback times than both LNG and ethanol.

Tests conducted on Stena Germanica and a chemical tanker owned by Waterfront Shipping have demonstrated that safety considerations are not a barrier to the use of methanol fuel systems on ships, says EMSA.



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People

Professor **Tekalign Mamo**, distinguished soil scientist and former Ethiopian State Minister of Agriculture has been awarded the 2016 IFA Norman Borlaug Award for his outstanding contribution to improving soil health and natural resources bases in Ethiopia, benefitting over 11 million smallholder farmers. Efforts spearheaded by professor Mamo to reduce the country's severe land degradation, soil acidity and nutrient deficiencies that hinder crop growth have played a critical role in Ethiopia's agricultural renaissance. Between 2000 and 2014, grain production tripled in Ethiopia, bolstering progress towards poverty and hunger reduction goals and earning the country recognition as one of the fastest growing economies in the world.

"I am honoured to receive this award, and am proud Ethiopia's leadership in addressing soil health issues is being recognised internationally," said professor Mamo. "Much remains to be done to continue Ethiopia's transformation and lift even more people out of poverty, but an accolade such as this serves as encouragement for my fellow citizens and African colleagues to continue this important journey."

"Professor Mamo's visionary work has demonstrated the immense impact improving soil health and natural resource bases can have for improving the food security and livelihoods of the most vulnerable," said Charlotte Hebebrand, Director General of the International Fertilizer Industry Association, which gives the IFA Norman Borlaug Award annually. "He thoroughly deserves this award for his outstanding commitment to soil health, to making relevant fertilizer more accessible and effective in the region and for putting a spotlight on the importance of developing more customized fertilizers."

Professor Mamo holds a PhD in soil chemistry and soil fertility from the University of Aberdeen in Scotland and in addition to his government roles, he has held academic, research, and senior management roles at Haramaya University. He has received several awards for the quality of his work, including the 2014 African Green Revolution Yara Award, and a UN FAO Special Global Ambassadorship role for 2015 International Year of Soils.

PhosAgro CEO **Andrey Guryev** has become president of the Russian Association of Fertiliser Producers (RAFP), and has been re-elected as Vice President Eastern Europe & Central Asia of the International Fertiliser Association (IFA). The re-appointment was announced at the closing press conference of the 84th IFA Annual Conference, which took place in Moscow for the first time and was attended by IFA Director General Charlotte Hebebrand and Andrey Guryev.

"The RAFP and the IFA share a number of goals, including promoting innovative agricultural technologies and helping farmers become more sophisticated in how they use fertilisers," Andrey Guryev said at the press conference. "In my position as IFA Vice President I will focus on sustainable growth of crop yields and reduction of environmental impact through the use of high-quality, ecologically friendly fertilisers and scientific methods of application."

Former Indian fertilizer tycoon **Pankaj Oswal** has returned to Australia after a five year absence to begin a legal case in the Victoria Supreme Court against ANZ bank and the receivers of Burrup Holdings – debts to ANZ forced the sale of Pankaj and his wife Radhika's share of Burrup Holdings in 2012, leading to its eventual purchase by Australian fertilizer firm Orica. The Oswals claim that their 65% share was undersold – at the time it was purchased for $560 million, and are suing ANZ for A$2.5 billion. The couple have been bared from leaving the country again by the Australian Tax Office, and are currently engaged in redeveloping their uncompleted mansion in Melbourne as luxury flats. However, during the hearing counsel for ANZ accused Pankaj Oswal of "misappropriating" more than A$150 million from his Burrup Holdings business over a three-year period, including payments of more than A$11 million for his mansion in Perth and A$8 million to a vegetarian restaurant chain in New York and London led by his wife Radhika. He presented a list of payments made by the Indian couple to activities not connected with their West Australian fertiliser business, representing an alleged breach of duty. The case is set to run for several months in what may be the largest dispute of its kind in the state.

Calendar 2016

SEPTEMBER

18-22
AIChE Ammonia Safety Symposium,
DENVER,
Colorado, USA
Contact: AIChE Customer Service
Tel: +1 800 242 4363/
+1 212 591 8100
Fax: +1 212 591 8888
Email: xpress@aiche.org

18-23
Ammonium Nitrate/Nitric Acid Conference,
EINDHOVEN,
Netherlands
Contact: Hans Reuvers, BASF/
Karl Hohenwarter, Borealis
Email: johannes.reuvers@basf.com/
karl.hohenwarter@borealisgroup.com

OCTOBER

11-13
29th AFA International Fertilizer Technology
Conference & Exhibition, TUNIS, Tunisia
Contact: Arab Fertilizer Association
Tel: +20 2 24172347
Email: info@afa.com.rg

16-19
Gasification and Syngas Technologies
Meeting, VANCOUVER, Canada
Contact: Gasification and Syngas
Technologies Council. Tel: +1 703 276 0110
Fax: +1 703 276 0141
Email: info@gasification-syngas.org
Web: www.gasification-syngas.org

25-27
IFA Production and International Trade and
IFA Crossroads Conferences, SINGAPORE
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

NOVEMBER

7-11
IFDC Granular Fertilizer Production
Workshop, BANGKOK, Thailand
Contact: IFDC. Tel: +1 256 381 6600
Email: training@ifdc.org

21-23
CRU Asia Nitrogen 2016 Conference,
JAKARTA, Indonesia. Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Fax: +44 (0) 20 7903 2172
Email: conferences@crugroup.com

2017

FEBRUARY

27-2 March
Ntrogen+Syngas 2017, LONDON, UK
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Fax: +44 (0) 20 7903 2172
Email: conferences@crugroup.com

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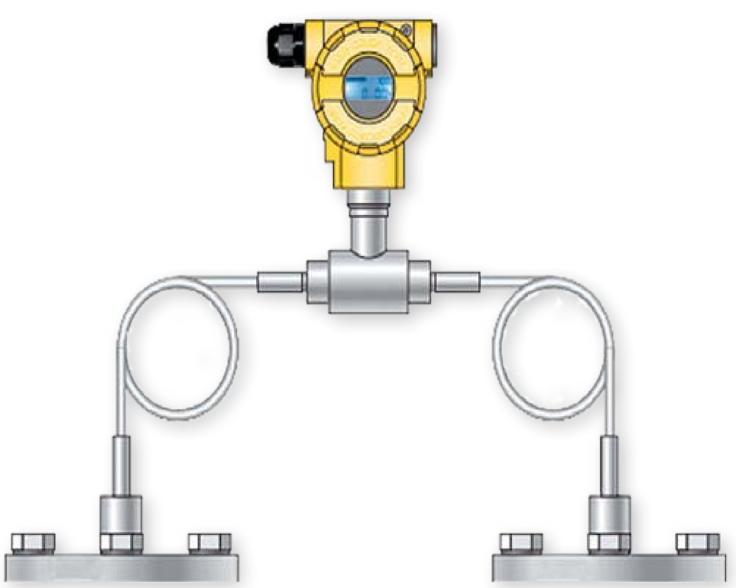
Plant Manager+

Problem No. 37 Faulty reactor pressure transmitter

Pressure transmitters have become essential parts of virtually all urea plants. Pressure measurement undoubtedly forms an important measurement in industrial process measurement and control. Pressure transmitters convert an applied pressure into an electrical signal, which is then transmitted to a device such as a computer, programmable logic controller, recorder, or digital meter to analyse the electrical signal and utilise it to display, record, or modify the device's pressure.

A schematic of a pressure transmitter is shown in the picture below left.



Mr Ab Samad Noraini from Petronas Fertilizer, Malaysia initiates a discussion of a familiar problem in urea plants: Our plant uses Saipem technology and we have experienced frequent faults with our reactor pressure transmitter. Because of this we often need to by-pass the protection of the trip logic of urea reactor.

Currently we are using a capillary type pressure transmitter. Does anyone else have similar problems and experiences that they can share and advise on modifications to solve the issue?

Mr Waheed Ahmad from FFC, Pakistan is first to respond: Different options are available to eliminate this problem. Please specify the position of the transmitter. How many times have you experienced tripping or failures?

Mr Girish Prakash from Tata chemicals Ltd, India joins the discussion: Reactor pressure transmitters are prone to failures but with certain precautions you can ensure a longer life. One of the easiest methods is to ensure proper working of tracings. In no case should they be in an isolated condition once start-up is under progress or the reactor is under draining.

Mr SK Gupta of IFFCO, India shares his experience: The reactor pressure transmitter installed in the CO_2 line, just after the control valve in the CO_2 line near the reactor, is always giving us problems. You can install the transmitters in a horizontal position by rotating the spool piece between the control valve and the reactor. This will reduce the frequency of failure.

Mr Mark Brouwer of UreaKnowHow.com, The Netherlands provides some more suggestions:
Other options to improve the reliability are:

- measure the reactor pressure in the ammonia line
- when measuring in a carbamate line, use tantalum as membrane material

Mr Gopala Krishna of Safco, Saudi Arabia, provides more information: You mentioned you are a using a capillary type transmitter but the most reliable transmitter is the pad type. Also when the transmitter is faulty its sensor element should show the minimum value; this measure can be taken by instrument people. Secondly, the high pressure reactor reflects the high pressure of the compressor, hence the reactor high pressure trip can be bypassed or reactor pressure influences more or less MV-01 (separator pressure) so the reactor high pressure trip can be shifted to the separator pressure trip.

Recently an accurate and reliable pad type pressure measurement has been developed, which is successfully in operation since September 2011 and is able to measure the pressure even in high pressure carbamate gas lines.

MrJavant Panvelkar of Zuari industries limited, India shares his experiences: We have the impulse tubing type pressure transmitter on the ammonia feed line and it is working fine. The only time it has gone wrong is during shutdowns when the reactor is in a boxed up condition, due to carbamate entering the impulse lines. This is easily cleared by flushing the lines. As previously mentioned, new technologies are available, but I feel the problem with the pad type is that if it fails it is not possible to to replace it online. Two pads probably will have to be used? We flush the transmitter lines once a month.

Mark provides more information: In stripping plants it is an advantage to measure the synthesis pressure as close as possible to the safety valves, i.e. in the carbamate gas line.
This new development makes that possible without risks of crystallisation and corrosion.

These special pad type pressure measurements are in operation since Sept 2011 without any problem.

Mr Kashif Naseem of SABIC, Saudi Arabia gives his suggestions: The most suitable place for this pressure transmitter is the ammonia feed line to the reactor.You can use a double pressure transmitter diaphragm type and make both at different pressure frequency. So make the trip point when both will appear.

The Badotherm extended type diaphragm seal with all wetted parts in zirconium.

Mr Ismail Ahmad of Ruwais Fertilizer, United Arab Emirates shares his experiences: We are using Stamicarbon technology and face a similar problem.However, we are going to replace the existing unit with a remote seal (extended diaphragm) type. It will be installed directly to the pipe, and the sensing diaphragm will be at same level as the piping surface, thus preventing the crystallization problem. Based on feedback from other plants using similar technology, the problem is resolved by using this transmitter. We will be installing the new transmitter this coming September.

Mark provides more information: Badotherm has successfully developed a safe and reliable membrane type of pressure and level measurement suitable for all urea process technologies. On stream times of already nearly two years have been achieved without any issues. This means significant costs can be avoided and additional profits can be gained with the innovative Badotherm diaphragm seals mounted to transmitters. ■

Correction

Please note there was an error in the labelling of the pictures in the last issue of *Plant Manager+ No. 36*. The correct captions are left picture shows corrosion of an internal part and right picture shows corrosion of a valve gland.

This series of discussions is compiled from a selection of round table topics discussed on the UreaKnowHow.com website. UreaKnowHow.com promotes the exchange of technical information to improve the performance and safety of urea plants. A wide range of round table discussions take place in the field of process design, operations, mechanical issues, maintenance, inspection, safety, environmental concerns, and product quality for urea, ammonia, nitric acid and other fertilizers.

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Iran has ambitious plans to develop its ammonia and methanol industries in the wake of the lifting of UN sanctions, but how realistic are they?

Iran after sanctions

In January this year, the UN International Atomic Energy Agency (IAEA) confirmed that Tehran had fulfilled its obligations under an agreement to limit its nuclear enrichment programme. This was the trigger for the progressive easing of international sanctions against the country which have steadily ramped up from 2006, as concerns over the country's nuclear ambitions have grown. The UN had mandated an arms embargo and asset freeze, and had added travel bans on individuals and sanctions on the provision of financial services. The US and EU, as well as some other states, had also imposed further sanctions on oil sales and oil equipment, and the US in particular had not only mandated sanctions on all companies doing business with Iran, it had also caused some difficulties by trying to extend those to companies outside the US that dealt with Iran that had US subsidiaries or operations.

Unravelling this complex web of international agreements and sanctions will take some time, but the thawing in US-Iranian relations begun by the replacement of more hawkish president Ahmedinejad with more moderate president Rouhani seems to be finally bearing serious fruit. Iran's central bank says lifting banking sanctions will allow $30 billion of foreign reserves frozen in accounts around the world to be brought back, and the Iran's GDP is expected to see a boost to 5% growth per annum over the period 2016-20 from an estimated 0% in 2015.

Gas production

While the country's oil production has been the first to see a boost from the easing of sanctions, perhaps greater long-term potential comes from Iran's huge natural gas reserves, the largest in the world at an estimated 34 trillion cubic metres in 2014, and representing around 18% of the world's gas. Although there are a considerable number of offshore and onshore gas fields along the southern coastline of Iran, about 67% of Iran's reserves are offshore, and 40% of the country's reserves are held in the single huge offshore South Pars Field (which extends across the maritime border with Qatar, where it is called the North Field). Development of South Pars has proceeded in spite of the various difficulties incurred by sanctions, with around 28 phases projected for the overall development of the field and associated onshore facilities, including gas and condensate production and downstream petrochemical works. Most of Phases 1-16 are now operational, and the pace of development has begun to accelerate as the prospects of sanctions being eased has made access to international markets more likely. Phases 17 and 18 are producing gas and due to be completed this year, and the gas processing/sweetening sections of Phases 20-21 are also expected on-stream soon, initially processing sour gas from Phases 6-8. Iran says that all of the gas phases should be up and running by the end of 2017 and the oil producing sections by 2018, although more conservative estimates put the final completion dates around 2021-22.

Iranian net natural gas production (i.e. minus that reinjected or flared, which has remained relatively constant over the past

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decade) has risen steadily from 102 bcm in 2005 to 192 bcm in 2015, according to BP, and consumption has kept pace with this rise. The country is in fact the world's third largest gas producer, after the US and Russia, although smaller by some considerable margin than both of those. There is around 7.8 bcm per year of gas exports to Turkey, but a similar amount (7.2 bcm) is imported from Turkmenistan, so that the country is neither a significant net exporter or importer of natural gas. About 50% of this gas is consumed for domestic heating, some 30% goes towards electrical power generation, and the remaining 20% goes to industry, with the country's ammonia and methanol plants consuming a significant proportion of this.

Nitrogen fertilizers

Iran has a reasonable sized nitrogen industry which has increasingly relied upon exports. There were ammonia-urea fertilizer plants built during the 1960s and 70s prior to the Iranian Revolution at Shiraz, serving the domestic Iranian market, together with Razi Chemical Industries, who developed a more export-oriented ammonia-urea complex at Bandar Imam on the Gulf. A second train was added at Shiraz in the 1980s, and a new plant was constructed at Bojnurd in the northeast of the country in the 1990s to serve the domestic market (see Figure 1). However, during the 21st century, the pace of development has picked up, with several new plants being constructed, including a 660,000 t/a ammonia-urea plant at Kermanshah, and a twin train ammonia-urea complex at Assaluyeh, which collectively more than doubled the country's nitrogen capacity and turned Iran into a significant exporter of urea. Nitrogen – mainly urea – has been the sole fertilizer export, as the country remains a net importer of P and K, although there has also been around 500,000 t/a of ammonia export, mainly to India.

Fig 1: **Existing and new syngas-based chemical plants in Iran**

KEY
Existing ammonia and methanol sites (see Table 1):
1. Bandar Imam (Razi, Fanavaran)
2. Assaluyeh (Zagros, Pardis)
3. Bojnurd (Khorasan)
4. Kermanshah (Kermanshah Pet. Co.)
5. Kharg Island (Kharg. Pet. Co.)
6. Shiraz (Shiraz Pet. Co.)

New and proposed ammonia/urea plants (see Tables 2 and 3)
New and proposed methanol plants

One of the imperatives for Iranian urea exports has been a collapse in domestic demand for nitrogen. Iran produced 4.3 million tonnes of urea in 2015, of which it consumed only 1.9 million tonnes. Iranian cereal production was 20 million t/a in 2015, and there is some small-scale export of wheat (200-500,000 t/a), but mainly the country is a net importer of cereal crops, with annual imports of 11-16 million tonnes of cereal. At the same time, nitrogen fertilizer application rates in Iran have fallen to 18kgN/hectare, compared to an average of 86kgN/ha for the rest of the world, and also compared to a pre-sanctions value of 53kgN/ha for Iran. There is thus plenty of potential for extra nitrogen demand within Iran. At the Nitrogen+Syngas conference in April, Iranian company Tappico predicted a 4% growth in Iranian fertilizer demand for 2016, rising to 5% per annum by 2020.

However, although Iran's exports of urea were restricted by sanctions, the country was still able to export to countries wholly or partially outside the sanctions regime, mainly to India – the destination for more than 80% of Iran's urea over the past few years, with some smaller volumes going to southeast Asia, Latin America, and even on occasion Europe. Even so, Iranian producers have had to sell at lower than prevailing market prices in order to win orders.

New production

In spite of the difficulties caused by its international isolation, Iran has tried to press ahead with plans to monetise its gas production, and during the past decade, Iran has pursued a number of new urea plant projects, mostly located along the coast, though including some (Marvdasht, Lordegan) in the interior. However, sanctions have made the licensing of technology and in particular the financing of these plants difficult. There are ten ammonia-urea plants at various stages of development in Iran, as shown in Table 2. Marvdasht and Pardis are the most advanced – both close to completion –

while some, such as Ardebil, Hormuz and Lavan, are barely begun. Although Iran regularly claims that all of these plants will proceed, there are rumours that those that are less then 10% complete are likely to be abandoned. Marvdasht is a wholly owned subsidiary of the Shiraz Petrochemical Company, with the ammonia licensor being Casale and the urea licensor Toyo. In addition to these plants already begun, there are also a number of new project proposals which are under discussion, as shown in Table 3. Kermanshah is an expansion at an existing site, while Chabahar is part of an Indo-Iranian joint development proposal, more on which below. The ammonium sulphate plant meanwhile would take existing ammonia and sulphuric acid production, and so must be considered more probable than some of the other plants under discussion.

If all of these projects came to fruition, they would represent an additional 13.5 million t/a of urea production in Iran, which would make Iran the third largest producer in the world, after only China and India's massive capacity, and the fifth largest nitrogen producer, with Russia and the USA also coming in higher. However, considerable barriers exist to getting all of this capacity on-stream, as we will discuss below.

Methanol

Aside from ammonia and downstream urea production, Iran's other major focus as gas-based chemical production goes has been methanol, as seen in Table 1 – Iran's methanol capacity now exceeds 5 million t/a. Methanol developments began in 1990 with the small 84,000 t/a plant at Shiraz, using Lurgi technology. Production there is aimed at domestic consumption. It was followed in 1999 by the Kharg Island methanol plant, another cooperation with Lurgi, with a capacity of 660,000, where production is aimed at the export market. A still larger plant followed at Fanavaran in 2004, using Topsoe technology, with 1.0 million t/a of capacity, about 80% of it going to export and the rest delivered domestically. Finally, the Zagros Petrochemical Company has developed two Lurgi mega-plants, each with 1.65 million t/a of capacity, the first of which came on-stream in 2008, the second in 2010. Output here is destined primarily for export.

As with ammonia, there are wildly ambitious plans for new methanol production, which could add 15 million t/a of capacity over the next decade if all of the plants

Table 1: **Existing gas-based chemical plants in Iran**

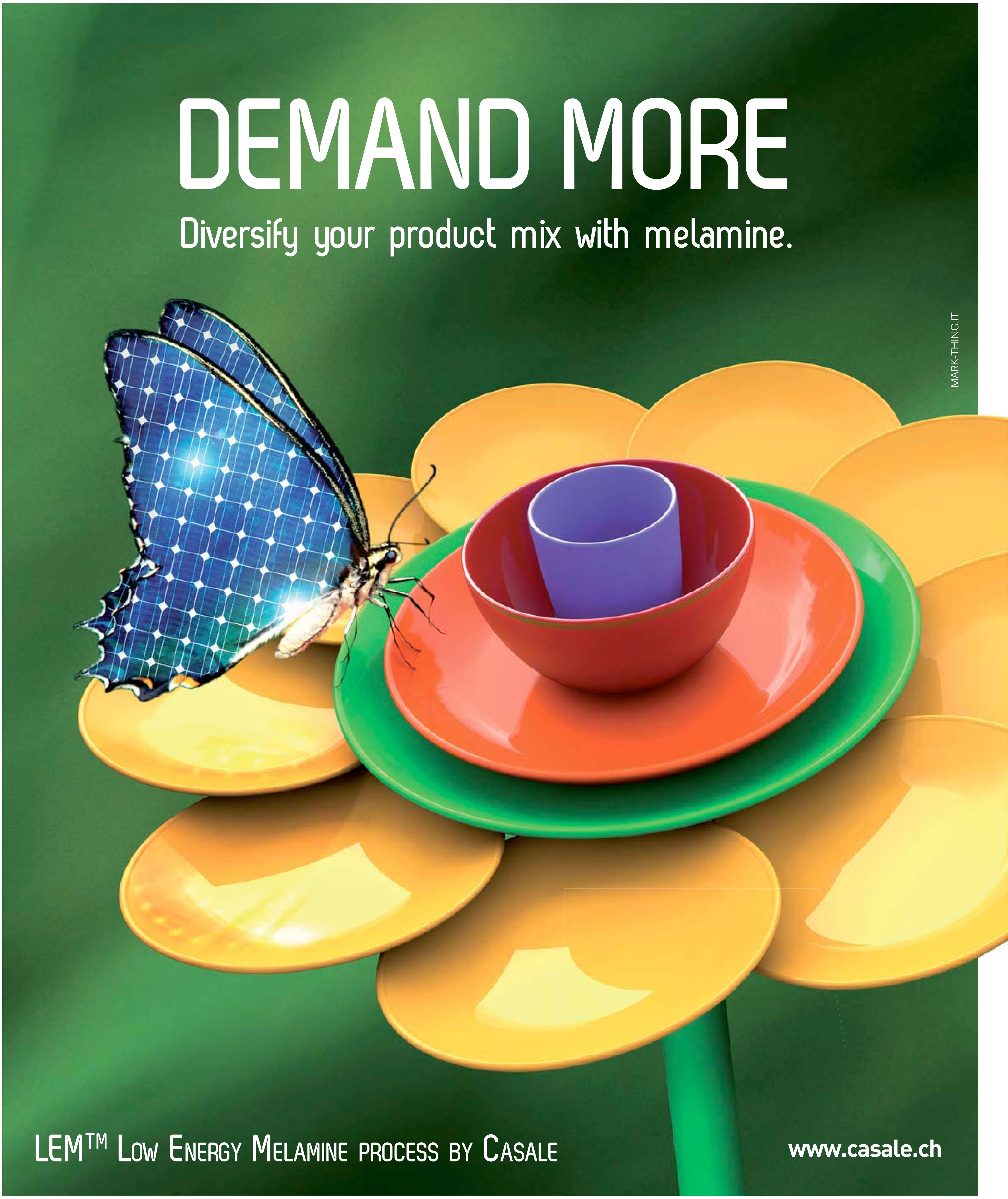
Company	Location	Product	Capacity (t/a)	Year operational
Fanaravan	Bandar Imam	Methanol	1,000,000	2004
Kermanshah	Kermanshah	Ammonia	396,000	2007
		Urea	660,000	2007
Kharg Pet. Co	Kharg I	Methanol	660,000	1999
Khorasan	Bojnurd	Ammonia	330,000	1996
		Urea	495,000	1996
Pardis	Assaluyeh	Ammonia	675,000	2007
		Ammonia	675,000	2009
		Urea	1,075,000	2007
		Urea	1,075,000	2009
Razi	Bandar Imam	Ammonia	330,000	1970
		Ammonia	330,000	1977
		Ammonia	677,000	2007
		Urea	595,000	1977
Shiraz	Shiraz	Ammonia	432,000	1985
		Urea	48,000	1963
		Urea	495,000	1985
		Methanol	84,000	1990
Zagros Pet. Co	Assaluyeh	Methanol	1,650,000	2006
		Methanol	1,650,000	2010

Table 2: **Urea plants under construction/development**

Company	Location	Capacity (t/a)	Status
Marvdasht Pet. Co	Marvdasht	1,075,000	95% complete
Pardis Pet. Co	Assaluyeh	1,075,000	87% complete
Lordegan Pet. Co	Lordegan	1,075,000	33% complete
Zanjan Pet. Co	Zanjan	1,075,000	22% complete
Hengam Pet. Co	Assaluyeh	1,075,000	19% complete
Golestan Pet. Co	Golestan	1,075,000	15% complete
Masjed Soleiman	Masjied	1,075,000	9% complete
Ardebil Pet. Co	Ardebil	1,075,000	5% complete
Hormuz Fert Co	Hormoz	n/a	5% complete
Lavan Chem Co	Lavan	n/a	2% complete

Table 3: **Proposed new nitrogen plants in Iran**

Company/location	Product	Capacity (t/a)
Kermanshah Pet. Co	Ammonia	400,000
	Urea	660,000
Sarakhs	Ammonia	680,000
	Urea	1,075,000
Chabahar	Ammonia	680,000
	Urea	1,075,000
Bandar-e Mahshahr	Ammonium sulphate	166,000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ended up being built. Plants under construction include Kaveh, Marjan, Kharg Island and Apadana, with capacities ranging from 1.3 to 2.4 million t/a each, and a 1.6 million t/a plant is under development at Pars. Marjan, at 1.65 million t/a, is reckoned to be 80% complete. Although the methanol market is growing faster than the ammonia market, with Chinese methanol to olefins production driving very rapid expansion there and elsewhere, the market would also struggle to cope with such a massive increase in tonnage.

Economics

While Iran has optimistic – most would say over-optimistic – plans for new urea and methanol plant development, there are serious questions as to whether the country is actually capable of building and financing so many plants, and how their economics will stack up. On the gas front, prices for feed gas have increased, and now stand at an equivalent of $1.50/MMBtu, but this is still low globally, and fuel gas is still available at $0.60/MMBtu, while gas from associated production at oil fields could be as cheap as $0.50/MMBtu. This makes Iran very competitive internationally from a feedstock point of view, and this forms most of the operating cost of ammonia and methanol plants. Likewise from a capital expenditure point of view, construction and labour costs are lower in Iran than most other places in the world, and there are established domestic construction and engineering firms such as PIDEC which are capable of doing the work. While it costs up to $2.0 billion to build a new world scale ammonia-urea plant in the US and $1.3 billion in some other regions, some argue this could be as low as $500 million in Iran. Costs of production of $100/t of urea have been floated, comparing very favourably even to current depressed international markets for fertilizer. However, as the US has found with its own massive leap in new chemical and petrochemical production, increasing numbers of projects tend to increase project costs exponentially, as steelmakers and fabricators run into capacity problems and there is a shortage of skilled personnel – something even Iran, with its large and relatively young population and high proportion of engineering graduates, is sure to have to cope with. The capacity to construct sophisticated rotary equipment, for example, like compressors and turbines is relatively limited. Having to import plant sections will begin to bump project costs up further.

However, the major issue is one of financing. Iran's petrochemical sector is mostly privatised and while there is considerable state assistance, economics are a real factor in spite of the gas and capex cost advantages. Some projects are already fully financed, but most of those that are still in the earlier stages of construction or development are short of cash and looking for new investment money, with many foreign companies still put off by the volatile political situation.

Joint ventures

In order to overcome these challenges, Iran has been keen to try and develop joint venture ownership structures to move projects forward. There has been a long history of trying to develop JV ammonia and methanol plants in the country, but so far there has been with little success. Plans for a collaboration with India for an ammonia-urea plant on Kharg Island foundered in the 1990s over gas price wrangles. The VenIran joint venture methanol plant developed with Venezuela was killed by Venezuela's slow slide into economic chaos and the sanctions regime on Iran, and various proposed collaborations with Russia, Oman, Indonesia and Turkey also all came to nothing. The easing of sanctions however has led to a reappraisal of the prospects for such ventures, and one at least now seems to be moving forward – the Chabahar ammonia-urea project in Table 3 is now being pursued as a joint venture plant with India. The project forms part of a development at the Chabahar Free Trade Zone, where India will also collaborate on. The privately owned Pasargad Energy Development Company (PEDC), a subsidiary of Iran's Bank Pasargad, has been shortlisted by the Indian participants in the project as their Iranian partner. PEDC owns land in the Chahbahar region, where India will be spending around $500 million to develop the port in Iran's south-eastern province of Sistan-Balochistan as a regional trade hub. The three Indian companies involved in the fertilizer plant are Rashtriya Chemicals and Fertilizers (RCF), Gujarat Narmada Fertilizers and Chemcials (GNFC) and Gujarat Chemicals and Fertilizers (GSFC).

Uncertainty remains

While Iran has the potential to become a major destination for investment in the sector, enthusiasm has been tempered with caution on various fronts. Firstly on a purely technical level, a number of key sanctions still remain. The US has lifted its so-called "secondary sanctions" – the ones that apply to non-US individuals or companies, but US "primary sanctions" will still ban US nationals and companies from engaging in business with Iran. On the financial side, dollar-based clearing restrictions remain in place, and US restrictions on dealing with the Republican Guard and its affiliates, including the Khatam al Anbia company, which is Iran's largest contractor in industrial and development projects, controlling over 800 subsidiaries including oilfield service companies. It will certainly be difficult if not impossible for US companies to deal with Iran, and project finance may need to be routed through countries with fewer restrictions, like China. These obstacles are not insuperable, but have the potential to cause delays and increase costs for investors.

Secondly, the political truce remains fragile and subject to shocks from either side. Iran faces presidential elections in 2017, and while president Rouhani should win a second term provided that people are seeing the benefits of the sanctions regime being lifted, there are many conservative elements in Iran opposed to a deal with the West. Likewise the rhetoric from Republican contender for the US presidency Donald Trump has in effect threatened to tear up the existing deal. These political risks could loom large for investors in the short term. Iran is said to be inserting a clause in contracts that foreign companies will not be released from contractual obligations should the US, EU or UN re-impose sanctions.

Summing up, then, Iran has abundant resources and grand plans. It is worth remembering that Iran was a bigger oil producer than Saudi Arabia prior to the revolution. There has been some justified scepticism about the pace of development that Iran seems keen to try and undertake, especially on the finance side, but at the Nitrogen+Syngas meeting in April in Berlin, Stamicarbon, a major licensor of the urea plants under development in Iran, said that it believes at least the two plants closest to completion will be complete, and probably two or three more over the next couple of years. This alone will double Iranian urea production. Likewise in a report on Iran consultancy IHS said that they believed at least 5 million t/a of new methanol capacity will come on-stream by 2025. Iran may not be about to flood world markets, but it's return will certainly make a major splash. ■

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New investment for Shchekinoazot

Russia's Shchekinoazot is to invest $1.5 billion in establishment of production of ammonia and urea during next several years, reports **Eugene Gerder**.

Shchekinoazot, one of Russia's leading fertilizer producers, has announced its plans to invest up to $1.5 billion in the building of a new complex for the production of ammonia and urea over the next few years. According to the company, the new complex will have the capacity to produce up to 730 000 t/a of ammonia and 1.2 million t/a of granulated urea, with construction beginning as soon as next year. Currently Shchekinoazot is looking for contractors for the project, and completing the design of a feasibility study of the new plant.

The new facility is expected to be commissioned at the company's existing site at the city of Schyokino, a town in Tula Oblast, close to Moscow. According to Anatoly Surba, CEO of Shchekinoazot, this will be one of the most expensive and complex projects that the company has undertaken over the past few years. Surba has also said that production at the new complex will fully comply with European and global standards. The company's initial plans called for licensing technologies from European companies, but due to existing sanctions, imports of such technologies to Russia is currently prohibited, which may force the company to revise its plans. It is planned that the majority of equipment for the plant will be provided by some German companies, possibly by thyssenkrupp Uhde Engineering Services GmbH, which is already a long-term partner for Shchekinoazot

The project will be implemented as part of the company's existing corporate development strategy, which began in 2005 and which is due to continue to 2028. To date, the total value of investments allocated as part of the implementation of this strategy has amounted to $650 million. The majority of funds have been provided by Gazprombank and Sberbank, Russia's largest banks.

Shchekinoazot 's existing methanol facility.

According to analysts at the Russian Ministry of Energy, the new project is very promising and may provide significant benefits to investors, taking into account that the demand for ammonia and urea in Russia is steadily growing, mainly due to the on-going recovery of the Russian economy from the 2008 financial crisis.

Export oriented

Shchekinoazot plans that the majority of future production of the plant and, especially the urea produced, will be exported abroad. In the case of urea, current global prices for it are in the region of $200/tonne, which may help the company to gain significant profits. According to sources in Shchekinoazot, the company is pinning big hopes on the project, as in recent years the production of nitrogen fertilizers has become very profitable for Russian companies, mainly due to the devaluation of the Russian rouble. The only obstacle that may prevent the beginning of active export of future production of the plant could be existing tariffs on the transportation of mineral fertilizers outside the country.

The majority of Russian plants for the production of nitrogen fertilizers were built during the Soviet times in1960-1980s years and were mostly designed to meet the domestic needs, rather than exports. Due to this, the majority of production facilities were established close to the largest nitrogen consumption regions in the country, which are located far away from the coast. That means that the cost of transportation usually accounts for a significant share in the total cost structure of Russian fertilizer producers.

However, part of the future production of the plant will be also supplied to the domestic market, as demand for nitrogen fertilizers in Russia has started to recover in recent years.

Finance issues

Implementation of the project is controlled by the Russian federal government. According to Russia's prime minister Dmitry Medvedev, successful commissioning of the plant will be part of the creation of a large cluster for the production of ammonia and urea in central Russia. It is planned that in addition to Shchekinoazot, the new cluster will include the capacities of the Azot company, Russia's second largest producer of nitrogen fertilizers and ammonia, part of Eurochem Holding.

However, while Shchekinoazot currently produces 500,000 t/a of sulphuric acid and 450,000 t/a of methanol, to date, the company has not operated its own production of urea and ammonia. In the meantime, analysts at the Russian Ministry of Energy believe that Shchekinoazot may face serious difficulties in attracting the required funds for the project. According to an official spokesman of Alexander Novak, Russia's Minister of Energy, raising the required $1.5 billion loan, amid the poor business environment in Russia, could be a very difficult task for Shchekinoazot, taking into account that the company is not considered by Russian banks as a major in the domestic fertilizer market, which also has a large portfolio of investment projects. This is despite the fact that the company remains highly profitable and has a good credit history. At present the total debt of Shchekinoazot is estimated at only 5.4 billion roubles (US$70 million), which is significantly lower than other Russian producers of fertilizers.

In the meantime, Shchekinoazot has already begun negotiations with domestic gas producers for the supply of gas for the new project, while the planned volumes of supplies are not disclosed. Currently the company has a contract with Gazprom Mezhregiongaz Tula, the local subsidiary of the Russian gas monopoly Gazprom, that is expected to meet the majority of its needs in gas for the new project. Shchekinoazot hopes that the supplies of relatively cheap gas will provide a competitive advantage to the company in the global market, as it will allow them to achieve significant savings on production costs. In addition, the company hopes to achieve savings on energy consumption, as high energy intensity has always been one of the major problem of the Russian industry of nitrogen fertilizers. The latter is expected to be achieved through the planned installation of new, modern equipment on the new plant. Currently Russian producers of ammonia use on average about 1,200 cubic meters of gas for the production of one tonne of ammonia, which is 30% higher the average figure for EU producers. However, due to the relative difference in gas prices, the direct costs of Russian producers are only around one half to one third that of European companies.

Other projects

Shchekinoazot remains one of Russia's leading chemical companies, whose annual output is estimated at more than 1 million tonnes of various chemical products per year. In addition to the ammonia and urea project, the company is currently continuing with the implementation of another project in the Tula region, which involves the construction of a complex for the production of methanol and ammonia and commissioning of which is scheduled for the beginning of 2018. The total volume of investment in the project is estimated at euro 270 million. The plant will have the capacity to produce 1,350 tonnes of methanol and 415 tonnes of ammonia per day.

Finally, as part of its development plans, Shchekinoazot is commissioning a new facility for the production of dimethyl ether (DME). The project is being jointly implemented with the German chemical company PCC SE, while the annual capacity of the new facility is expected to reach 20,000 t/a. The new plant is expected to be commissioned at the end of the current year. ■

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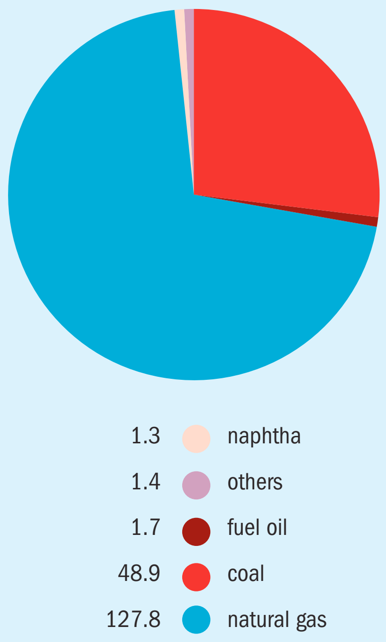
Feedstock economics

Feedstock economics continue to be the largest slice of operating cost for ammonia and methanol producers. While unconventional gas production and the slowdown in the world economy have put gas back in the driving seat, non-market mechanisms continue to distort gas pricing outside Europe and North America.

Various feedstock options are available for those wishing to make syngas, from steam reforming or partial oxidation of natural gas through gasification of various heavy feedstocks such as coal, heavy fuel oils, petroleum coke, biomass or industrial waste, and reforming of naphtha. Hydrogen can also be electrolytically split from water as a source for ammonia production. However, as the International Fertilizer Industry Association's (IFA's) most recent survey of ammonia capacities shows (Figure 1), coal and natural gas are by far the most prevalent. The small remaining naphtha capacity is exclusively in India, and those plants are now in the process of conversion to natural gas feed because of the relatively high cost of naphtha, and the fuel oil plants are generally smaller and older facilities. There are a couple of plants with the capacity for hydrogen generation from electrolysis, but they are mostly closed down due to the relatively high cost of electricity and the requirement for the power to be used for domestic rather than industrial uses. Generation from industrial waste, biomass or alternative energy sources is still in its infancy. Of the coal-based capacity, there are some isolated coal-based plants in Japan, Vietnam, South Africa and the US, as well as a couple of plants based on petroleum coke gasification (e.g. Coffeyville in Kansas), but by and large coal-based ammonia is a Chinese phenomenon, with 95% of coal-based capacity located there.

On the methanol side, there is a similar split, as shown in Figure 2. Again, there are some isolated coal and coke-based plants in e.g. the US and Germany, but again almost all of the coal-based capacity is in China. That also goes for the coke oven gas-based plants, which are also a Chinese phenomenon.

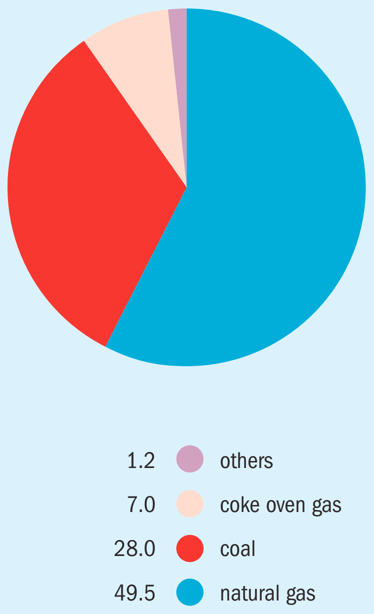
Fig 1: **Ammonia capacity by feedstock, 2016**



Total: 181.1 million tonnes

Source: IFA

Fig 2: **Methanol capacity by feedstock, 2016**



Total: 85.7 million tonnes

Source: MMSA

Gas vs coal

Gas took over from coal as the predominant feedstock for syngas generation in the 1960s and 70s, as gas production and exploration boomed. It has several advantages, the prime one being that, as a gas, there is no capital-intensive requirement for an expensive front-end processing section in order to pulverise and gasify a solid feedstock, although it generally still requires some pre-treatment, especially to remove sulphur which can poison catalysts etc. It is also often available in large, concentrated quantities, and hence lends itself to economies of scale in terms of production. Historically, it also tended to be a cheap feedstock, as it could not be as easily transported as coal – a bulk solid – and instead required expensive pipelines or even more expensive liquefaction plants and refrigerated ships to bring to market. This led to the concept of so-called 'stranded' gas, far from end use markets, and export-oriented ammonia and methanol plants began to gravitate to such stranded gas, in locations such as the Middle East, Trinidad, Indonesia etc.

However, in spite of some efficiency gains in e.g. the US and UK in terms of gas distribution caused by deregulation of markets and "gas-on-gas" competition, gas became a victim of its own success, especially because the same advantages which made it a good feedstock for syngas production also made it a good fuel for power generation. Gas turbines were more efficient than coal-fired power stations and faster to build, and became an easy way for rapidly industrialising countries in Asia and Latin America to build new power capacity. It also became seen as a 'greener' fuel than coal, which led to it being increasingly adopted in Europe. The rise of gas in Asia prompted the rapid growth of the market for liquefied natural gas (LNG), and this in turn changed the gas market. With electricity customers prepared to pay increasingly higher prices, LNG and power production became the favoured use for gas, and its use for chemical production increasingly attracted an opportunity cost.

These developments meant that 'stranded' gas became an increasingly elusive commodity as LNG plants and pipelines proliferated and gas started to become more and more expensive. Some countries reacted to this by controlling or subsidising natural gas prices, but in some markets, such as Europe and North America, the increasing expense of gas led to people taking a renewed interest in solid feedstocks, especially coal, which has become cheaper as it falls out of favour as a power plant feedstock. In particular, gasification can use cheaper grades of coal which are often unsuitable for power generation, such as bituminous coal, or coal with a high ash content. With gas expensive or unavailable in key regions, there was interest in coal gasification across Asia, in countries like China, India, Vietnam and Indonesia, as well as in North America and Australia.

But gas markets have been transformed once again over the past decade by the rise of 'unconventional' gas production, often using hydraulic fracturing techniques as in shale gas or tight gas production, or other pressure-dependent processes like coalbed methane desorption. The market which has seen the greatest impact of this has of course been the US, which has moved from being a major gas importer to, earlier this year, sending its first cargo of LNG overseas. However, coalbed methane production has also been extremely important in coal-rich countries like India, China and Australia. India is about to commission its first coalbed methane-fed urea plant in West Bengal, although the plant has been delayed due to delays in getting the gas on-stream.

At the same time, coal's higher CO_2 penalty has become increasingly important from a regulatory point of view, and attempts to ameliorate this via carbon capture and storage, or underground coal gasification have not managed to overcome the difficult technical and economic barriers to development. Even China, which has seen coal as a way to reduce its dependency on imported raw materials, seems to be beginning to recognise the limits of growth using coal-fed plants.

Gas prices

The slowdown in the commodities market which has occurred over the past couple of years, caused by China's pause in the breakneck pace of its own industrialisation, has had a knock-on effect on gas prices, especially liquefied natural gas prices, which had previously been propped up by the after-effects of the Fukushima nuclear disaster in Japan, and Japan's consequent shutdown of its nuclear power generation capacity and switch to gas-based generation. But base prices take their cue from the US gas market, particularly the Henry Hub trading point benchmark, and these have been falling steadily due to the US boom in shale gas production. US natural gas production has risen by 50% over the past decade, from 511 bcm in 2006 to 767 bcm in 2015, according to BP. This puts production only 11 bcm shy of consumption, so that the US is now essentially self-sufficient in gas. At the same time, US gas prices have fallen, and now stand at around \$2.00/MMBtu or just under for the Henry Hub.

Gas prices in the US and Canada are set by so-called 'gas on gas' competition, via trading hubs and futures markets, and outside North America, only the UK has full gas-on-gas (GoG) competition. The main alternatives to GoG competition are via an oil price link or escalator (OPE), whereby gas prices are linked to international oil prices, a so-called bilateral monopoly, where large sellers and buyers agree to fix long-term contracts (also often linked to international oil prices), a price set via a netback mechanism from a final product, such as ammonia or methanol, or a government regulated price. The prevailing price structure is very much dependent upon the region you are in.

In North America, as we have seen, GoG is the dominant pricing mechanism. In Europe, prices used to be mainly set via oil price escalators, but GoG is spreading as the EU liberalises its internal gas markets. The International Gas Union calculated that in 2015, 60% of European gas was traded as GoG, with trading hubs like the UK National Balance Point (NBP) and Zeebrugge now setting prices across the continent. OPE by contrast now accounts for only 30% of gas bought in Europe, with GoG steadily spreading from the more liberalised markets of northwest Europe into central and even eastern Europe. The main holdout for oil-linked contracts is now in Mediterranean countries.

Across Asia, however, OPE continues to spread, driven by the steady growth in the LNG market, which tends to be priced according to oil. GoG trade accounts for less than 20% of gas purchasing in the Asia-Pacific region, with 55% on OPE and most of the rest controlled or subsidised in some manner, while in China and other mainland Asian countries like India, the OPE figure is 45-50% and the rest controlled or subsidised.

There has been much discussion about the prospect of developing a gas trading hub in Asia to rival Europe and North America. This trading hub would be likely to be based around LNG cargoes, which are the dominant means of sending gas around the region, and Singapore is the most promising candidate, with LNG cargoes imported, exported and traded on a daily basis. However, at the moment these moves are still in their infancy, and hence the link to oil prices remains a dominant one.

The effect of this on manufacturers of gas-based chemicals can be seen in Table 1, which compares dominant pricing mechanism by region, and the average wholesale gas price across the region for last year. One of the striking things about the final column is that the collapse in oil prices has caused a dramatic reduction in gas prices in regions where LNG and oil price escalators are common, such as the Asia-Pacific region. The 2015 wholesale price of around \$8.00/MMBtu compares with an average of \$12.00/MMBtu for 2014. Note that these figures for how much gas is bought via different price mechanisms is for overall consumption – Europe's domestic production is mainly traded as GoG, but because Europe produces much less gas than it consumes, the gas it imports, mainly via pipeline from Russia, but increasingly also as LNG into ports in western and southern Europe, are bought mainly on oil price linked contracts, and this ups Europe's overall OPE figure to 30%, and also pushes its average wholesale price close to that for Asia, where OPE is dominant.

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Table 1: **Regional gas price differentials, wholesale prices**

Region	Oil price escalator	Gas on gas	Controlled prices	Average price, 2015
North America	0%	100%	0%	$2.50/MMBtu
Europe	30%	60%	10%	$7.00/MMBtu
Asia-Pacific	60%	15%	25%	$8.00/MMBtu
Latin America	30%	20%	50%	$4.00/MMBtu
FSU	5%	25%	70%	$2.00/MMBtu
Africa	10%	10%	80%	$3.00/MMBtu
Middle East	5%	0%	95%	$2.00/MMBtu

Source: IGU

Other regions, Latin America, the former Soviet countries, Africa and the Middle East show steadily increasing proportion of gas that is controlled pricing, and here economics and politics mix. It is also worth noting that the strength of the dollar has pushed down prices in dollar terms, especially in Russia.

Coal prices

Coal prices have been driven by China, which is its largest consumer – China consumes 50% of the world's coal. However, the rise in gas production in the US and the fall in gas prices has also significantly reduced demand for coal in the US, which is also a major producer, and pushed large tonnages of American coal onto the world market, contributing to oversupply, especially as China's demand has cooled. Coal prices have more than halved from their peak of $120/t in 2011-12 to around $55/t at present for thermal coal on the international market.

Coal prices are mainly a factor for the Chinese market – as noted above, China has built huge volumes of ammonia and methanol production based on domestic coal feedstock, and coal represents about 70% of China's domestic ammonia production (and a higher proportion of methanol). Coal prices have fallen in China because of a glut of production, but in addition to this, much of the new capacity in China is built with greater energy efficiency in mind and has also been able to take advantage of low grade bituminous coal, which has improved its pricing position still further. According to Integer Research, around 75% of China's coal-based ammonia capacity can operate on bituminous coal, which can be bought for up to a 30% discount on conventional anthracite. Bituminous coal prices in China are as low as $1.50/MMBtu equivalent. This makes Chinese urea production costs as low as $200/t, and has been a major factor in the slide of urea prices globally.

But China is now acknowledging that it has overbuilt urea capacity, and furthermore that urea is often over-applied on fields. The Chinese government has set itself a target of cutting nitrogen consumption by 8% over the current five year plan, and stabilising fertilizer use by 2020. Any more ammonia capacity in China is therefore likely to mainly replace older, less efficient plants.

On the methanol side, conversely, China has used its coal to generate methanol for methanol to olefins production, and here there are still a large number of projects under development, as well as Chinese sponsorship of gas-based projects elsewhere (eg the west coast of the US) to feed Chinese MTO plants.

> “However, pricing is fairly irrelevant if you can't actually source the gas in the first place.

Gas availability

Every $1.00/MMBtu in gas price represents approximately a $25/t increase in cash cost of production for a urea producer, or $33/t for the cash cost of production of an ammonia or methanol producer, and this has pushed export-oriented production towards lower-cost 'stranded' gas locations and helped fuel capacity in major consumers based around self-sufficiency where gas prices are kept cheap by government decree. However, pricing is fairly irrelevant if you can't actually source the gas in the first place. This is a major issue for many Asian countries, especially places like India and Pakistan, but also, for example China, where in spite of expansions in sour gas and coalbed methane production, gas is not available for large scale industrial projects.

Meanwhile, countries which were once 'stranded' gas locations like Indonesia and Trinidad have found that production has not kept pace with LNG exports and rising domestic demand for gas – often because of low, controlled prices that disincentivise new gas exploration and production. Even the Middle East, where gas was once abundantly available for new ammonia and methanol projects, is finding that rising demand (or in Qatar's case the lure of the LNG market) is reducing gas availability and pushing up costs. Saudi Arabia and Abu Dhabi have turned to sour gas production to satisfy demand, bringing large extra costs in terms of safety, corrosion resistant materials and hydrogen sulphide and carbon dioxide extraction from the gas.

In spite of tight gas and coalbed methane production in some other countries, the shale gas boom in the United States has still not yet managed to catch on worldwide. Europe frets about pollution, carbon emissions and well organised local opposition to fracking, while China has a shortage of water to pump into the wells.

In this environment, the number of places where gas is available for new production seems to shrink with every passing year. Outside the US and the former Soviet states of Russia and central Asia, only Iran, perhaps Malaysia and some parts of South America have the gas to spare, as well as Africa, one of the few places where large gas fields are still being discovered. Here the gas can still be regarded as 'stranded', but lack of infrastructure and political risk can make developing multi-billion dollar projects daunting. ■

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Issues with ammonia transportation

Ammonia transport by rail faces increasing scrutiny, especially in North America, in the wake of several high profile rail accidents involving oil and petrochemical products.

While most ammonia is consumed at the point of production, in urea, phosphate or nitric acid plants, a considerable volume is moved around, within and between countries. This is a particular facet of the US market, which consumes 16 million t/a of ammonia, of which 4 million t/a is distributed to farms for direct application as a fertilizer, and of which 5 million t/a are imported, mainly for use in ammonium phosphate production.

While use of direct application ammonia has declined, it is still a major slice of US demand, and this means that large volumes of ammonia are transported around the US, by pipeline, barge, rail and truck. Rail has generally been regarded as one of the safest ways of transporting ammonia, as trains can take large volumes at a time without the need for many driver hours of truck transport, which offers more potential for accident. However, rail transport in general and ammonia transport in particular has come under increasing scrutiny as a result of a spate of rail accidents involving oil and chemical spillages and a more general concern about transport of toxic liquids/gases. Ammonia and chlorine (the latter from chlor-alkali plants and mainly destined for water purification) between them represent 85% of the tonnage of so-called ‘Toxic Inhalation Hazards’ (TIH) which are carried by rail in the US.

Rail accidents

The issue has come to the fore in the US after a number of high profile rail accidents in North America, particularly involving the carriage of crude oil by rail, including the February 2015 derailment of a 107-car train at Mount Carbon, Virginia, and the 2013 disaster at Lac Megantic in Quebec in which a runaway train derailed in the centre of town, spilling 1.6 million gallons of oil and killing 47 people in the subsequent fire. Altogether the US and Canada have seen 14 such incidents in the past two years, the most recent in June this year in Oregon’s Columbia River Gorge, leading to ever more urgent calls to improve rail safety and the transport of dangerous goods by rail. In total, accidents have increased sixteen-fold between 2010 and 2014, as ever more volumes of crude are carried by rail. In part this has been due to the failure to agree on pipelines like Keystone XL to carry syncrude from the oil sands patch of northern Alberta to refineries in the US, but also due to the boom in US tight oil production that has been opened up by fracking techniques.

Positive train control

The accidents focused attention on rail safety, an in particular a train collision avoidance system called Positive Train Control (PTC). PTC is a series of advanced communications technologies using GPS and other sensors to continuously monitor and control train movements to prevent accidents and enhance rail safety, automatically applying brakes if a train moves into a potentially dangerous position. In 2008, Congress mandated PTC in its Rail Safety Improvement Act, in response to a previous series of accidents between 2002 and 2008, culminating in the collision of a Metrolink passenger train and a Union Pacific freight train in California in September 2008, which resulted in the deaths of 25 and injuries to more than 135 passengers. The implementation deadline set in the 2008 act was December 2015, and hence in the light of recent accidents there was considerable pressure on government to make sure that this was strictly adhered to.

However, as the deadline approached last year it became clear that train operators had not yet completed implementation of the hugely costly investment to apply PTC to all carriages and cars, and a number, including Amtrak, warned that they would have to suspend operations. Another railway company, Norfolk Southern, said at the end of last year that it would stop shipping chlorine and ammonia across its network, and farmers and fertilizer producers faced the prospect of having ammonia rail shipments completely suspended as of January 2016. This lead to intense lobbying by rail and chemical companies. In late 2015 a letter was sent by TFI and 39 other agriculture organizations, including 16 national associations and regional agriculture organisations representing 27 states urging Congress to pass PTC extension legislation. As a result, Congress eventually relented and passed a rider to a highways bill in late 2015 which gave a three year extension to the deadline, to the end of 2018.

The bill mandated PTC for all lines which carry passengers or toxic inhalation hazards (TIH), which, as discussed, mainly involves transport of, anhydrous ammonia. However, while the American Association of Railroads (AAR) estimates that rail companies had spent more than $6 billion implementing PTC as of the end of 2015, some estimates put the total cost of implementation at $10 billion. Electronic braking systems cost $8-10,000 per rail car, and there are also trackside components. The technologies are complicated, and obtaining the requisite radio frequencies for wireless communications along the entire rail network has proven difficult. Some delays came from federal agencies. Full implementation requires installation of about 35,000 wayside interface units and 25,000 poles to transmit PTC signals, and in May 2013 the Federal Communications Commission halted construction of these structures for over a year until the agency could develop a process to review potential historic preservation and tribal impacts. In another instance, the Federal Railroad Administration took seven months to review a safety plan submitted by a railroad.

But some have argued that the system is overly complicated and would not prevent many of the accidents that it is being introduced in response to, which are often caused by broken rails. The issue, it is claimed, is really one of rail maintenance and lack of investment in track. It is also argued that the weight of the extra crude cars being carried has caused increased and unforeseen wear on the track.

Tank car strength

A train carrying ammonia (as well as other chemicals) derailed at Minot, North Dakota in 2002, leading to five of the eleven ammonia tank cars being breached and releasing their contents. One person died from ammonia inhalation. The incident led to a 2005 National Transportation Safety Board (NTSB) recommendation for stronger tank cars for pressurised liquids/gases, and in January 2009 a notice of final rulemaking was issued. The rule set an interim standard for all new rail cars that were constructed, and set a speed limit of 50 mph for loaded TIH cars. It also led to the Next Generation Tank Car Project, which aims "to provide the technical basis for rulemaking on enhanced and alternative performance standards for tank cars and review of new and innovative designs" via validating computer models against real world impact test results.

The oil accidents mentioned above have also led to criticism of the DOT-111 tank car standard for carrying flammable liquids, and a move to a stronger, double walled design is also on the cards. Trains carrying large amounts of crude oil will be restricted to 30 mile per hour speeds if they don't have the new PTC electronic brakes installed by 2021. Other flammable liquids, including ethanol in high volumes would be speed-restricted after 2023. Trains with either a block of 20 or more cars or a total of 35 or more cars of flammable liquid will be required to use a second locomotive to help with braking.

Alternatives

Even before the current focus on ammonia rail transport, there has been scrutiny of the large scale movement of ammonia. Railway companies in particular are concerned by the potential liability they face in the event of an accident, and some have increased carriage rates to try and force hazardous material products off of their lines. In 2014, The Fertilizer Institute reckoned that since 2005, ammonia freight rates on some carriers have increased by as much as 400%. While the fertilizer industry and agricultural retailers have so far fought successfully to keep ammonia travelling by rail, last year's threatened shutdown has focused minds on what alternatives there might be.

There alternative modes of transport. Road transport is generally riskier than rail, and although the volumes involved in any single accident would be much smaller, the number of trucks required to replace the current ammonia rail car fleet would multiply the risks up many times over, and increase the exposure of more heavily populated areas. However, ammonia is also transported by barge – around 1.7 million t/a of it. Each barge can handle around 30 rail cars worth of ammonia (ca 2,500t) and generally further from populated areas. The presence of large volumes of water also helps absorb ammonia spills and leaks.

Additionally, there are two major ammonia pipeline networks in the US; the NuStar pipeline runs from the Gulf Coast to Indiana and Nebraska, carrying around 2 million t/a, while the Magellan pipeline runs from Texas to Minnesota and carries 900,000 t/a. Pipelines have the best safety record in terms of ammonia releases, but construction of a network capable of handling present rail transport would involve considerable investment and expense and probably price ammonia too high for end users.

Localised production

At the 2012 AIChE Ammonia Safety Symposium, Uhde (as was – now thyssenkrupp Industrial Solutions) suggested another potential solution to this conundrum – small-scale production of ammonia close to the point of use. The idea was to design ammonia plants which get around the problem of lack of economy of scale provided by large scale plants to make the production economically viable. The company considered plants of 300-500 t/d capacity, and its economic analysis suggested that such plants were viable when ammonia transport costs from large scale plants were $100/t or greater (in parts of the US agricultural belt the actual cost can be $300/t or more).

The proliferation of shale gas production has made the feedstock for such plants all the cheaper and more readily available, and in a way, the new plants being built in states like North Dakota, Iowa and Indiana are based on this exact solution, although generally of larger, 'world-scale' capacities than the smaller/medium scale plants envisaged by Uhde.

Product switch

Finally, farmers could of course simply switch from using ammonia to other products, either urea or urea ammonium nitrate. Again, in a sense this is already happening. US consumption of direct application ammonia has fallen from a peak of around 6 million t/a in the 1980s to around 4 million t/a now. At the same time, urea consumption has risen to 6 million t/a from only 2 million t/a, and UAN solution consumption has more than doubled to 3.2 million tonnes N. UAN in particular, as a liquid, can be applied using the same handling systems and tanks as ammonia, but without the potential accident hazards. Its disadvantage is that it is mostly water, and so the concentration of nitrogen in a UAN solution is only 28-32%, as opposed to 82% for pure ammonia. However, in a future where rail transport of ammonia becomes prohibitively expensive, this disadvantage may be outweighed by the extra cost burden of ammonia use. ■

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1970s 'cube houses' in Rotterdam.

Advances in urea technology

Stamicarbon's 13th urea symposium was held in Rotterdam from May 9th-12th this year, highlighting as usual new products and developments in urea and associated technologies.

Now under the umbrella of Maire Tecnimont, Stamicarbon prides itself on being an innovation-led company, with 8% of its income spent on research and development, values which Maire Tecnimont CEO Pierroberto Folgero was keen to stress aligned closely with Stamicarbon's parent company. While welcoming delegates to Stamicarbon's 13th urea technology symposium in Rotterdam, he and Stamicarbon CEO Pejman Djavidan noted that these are difficult times in commodity markets, and companies need entrepreneurship, technical excellent, value and resilience to succeed.

In an innovative development in its own right, the conference included an interactive app for delegates' mobile phones, allowing speakers to pose questions of the audience and get statistical feedback in real time. One of the more illuminating straw polls concerned the major drivers that plant operators felt were the prime motivation for revamping a urea plant, which broke down as follows; no plans to revamp – 30%; deteriorating/ageing equipment – 20%; market drivers requiring higher capacity or new products – 40%; and tightening regulations on emissions etc – 10%.

Market outlook

Tom Tiethof, Stamicarbon's market and business intelligence manager, began the conference with a presentation outlining the company's appreciation of the current urea market. As urea is mostly (84%) destined for fertilizer use, it depends on fertilizer markets, where demand fundamentals remains sound and growth continues at ca 3.1% per annum, with total urea demand rising from 166 million t/a in 2014 to 194 million t/a in 2019. This compares to about 0.8% per year for UAN, 2% for AN, and 2.5% for total nitrogen demand. Industrial demand meanwhile is growing at 7% per year, for resins, diesel exhaust fluid etc. Most (58%) of urea demand growth is in Asia, especially southeast Asia with 22% in the Americas, mostly South America, and 11% in Europe. China and India have seen strong growth but are maturing markets.

On the supply side, the key drivers are low feedstock costs in the US (to supply domestic demand) and FSU (for export or replacement of old capacity), gas monetisation in the Middle East (again export oriented) and self-sufficiency in China and potentially India. While there is a glut of new capacity at present, there are delays – sometimes significant delays – for longer term projects like KIMA in Egypt, Olam in Gabon, Dangote in Nigeria and Tres Lagoas in Brazil, and the overcapacity in the market was expected to peak in 2017 and decline thereafter, with a market rebalance during 2018 and the industry heading back towards its long-term operating rate by 2020. Meanwhile trade is changing, with the US, previously a major importer, becoming self-sufficient by 2020. The excess may get pushed towards Latin America and put pressure on Chinese producers, where some smaller, less efficient plants may close – up to 6 million t/a of capacity according to some estimates.

Technology

Over the course of the three days, numerous technical papers were presented detailing current and especially future urea technologies. Some of the highlights of the new technical developments follow.

New steels

Safurex, the corrosion-resistant steel that is the product of Stamicarbon's long-standing collaboration with Sweden's Sandvik, has become a standard component of Stamicarbon urea plants, assisted by the development of *Safurex*-specific welding techniques with Austrian fabricator SBN. Now Sandvik and Stamicarbon have taken the *Safurex* concept further, with a speciality grade suitable for use under even more severe process conditions such as the heat exchanger tubes of the high pressure stripper. While other parts of the synthesis loop would be constructed of 'standard' *Safurex*, now rebranded as *Safurex-∞*, this new so-called *Safurex-** can also be used in non-Stamicarbon plants such as thermal stripping plants. There is also a new production technique developed called hot isostatic pressing which produces so-called *Safurex-°* ("degree"), which has excellent mechanical properties at low temperatures.

Multi-product granulation

Although readers are no doubt familiar with urea ammonium nitrate (UAN), usually produced as a solution. However, at the conference Stamicarbon instead unveiled a process for the granulation of solid urea ammonium sulphate (UAS). The logic behind this is the increasing requirement for sulphur as a fertilizer in its own right, and that fact that in ammonium sulphate both the nitrogen and sulphur are present in a form more easily taken up by plants than urea, while the urea component gives the overall fertilizer greater nitrogen content than ammonium sulphate on its own. The process mixes urea melt, urea solution and solid ammonium sulphate, the latter can be included in any concentration from 0-50%, but otherwise uses the current Stamicarbon urea granulation process as its backbone. If 50% AS is used, the final product analysis is 33.5% N and 12% S in 3mm granules otherwise similar to conventional urea granules. The first project using the process is under development with Eurochem in Russia. Basic engineering is complete, an EPC contractor has been selected, and the procurement process has begun.

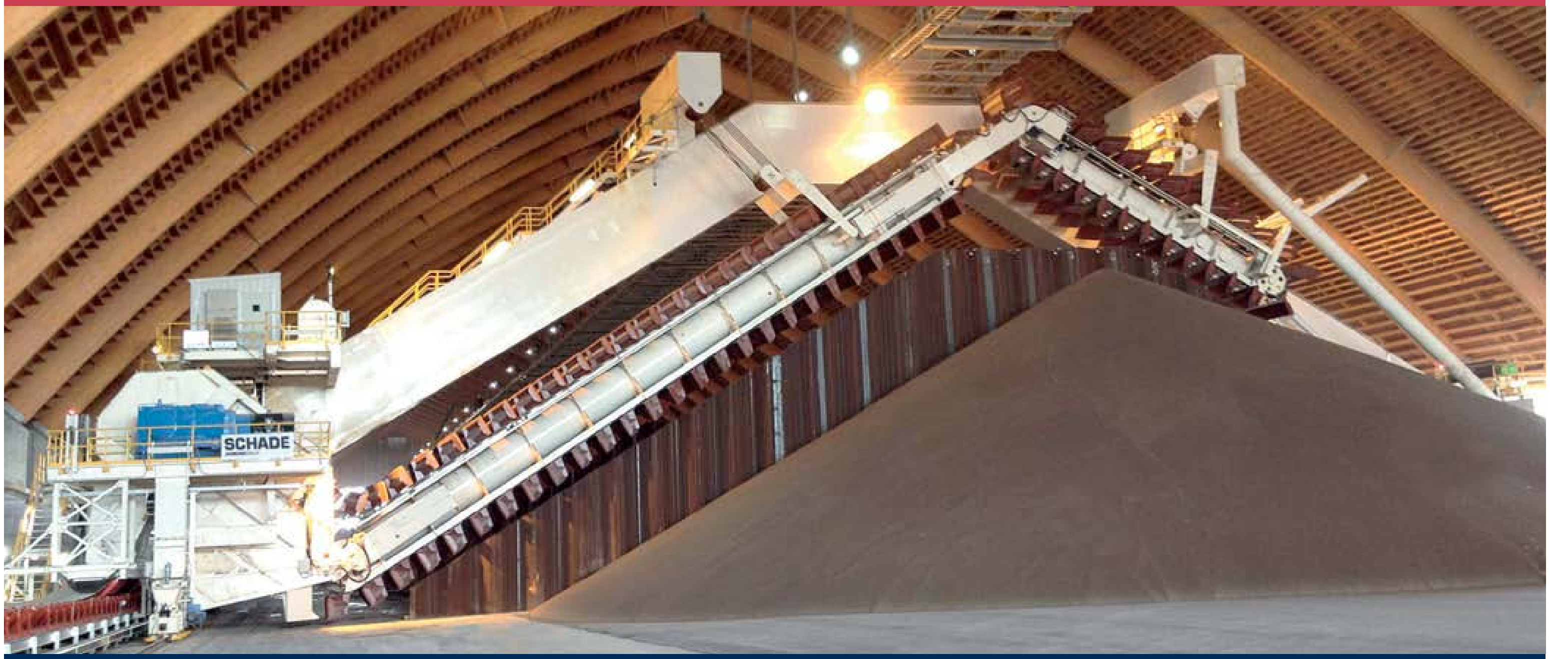
Stamicarbon also say that this process can be used as the basis of what they describe as 'multi-product granulation', incorporating zinc and other micronutrients such as boron, copper, iron, manganese and molybdenum.

New finishing technology

Leon Posma of Stamicarbon explained work that had been conducted on development of a new dry fertilizer finishing technology. The technology makes use of a section of the urea-water phase diagram where there is no mixture between the two substances, between 80-100°C and at a pressure below 0.3 bar. When a urea-water mixture is flashed at a pressure below 0.3 bar, all of the urea crystallises, releasing heat, and all of the water evaporates (consuming heat). The process avoids the use of exhaust air (which must be scrubbed of urea and ammonia) and the wasteful release of heat that occurs in traditional prilling and granulation plants. The urea formed also has far lower biuret concentration than for a conventional process. However, the solid urea forms as a fine powder rather than a granule. While this is ideal for going on to produce a solution of diesel exhaust fluid (AdBlue), the urea must be further shaped before it would be usable as a farm-ready fertilizer. In some regions farmers use so-called 'super granules', produced by crushing urea prills and compacting the fragments, and it is easy enough to form the dry flash produced urea into such super-granules, but in order to produce a product comparable with prills or granules in terms of caking tendency, crush strength, composition, etc, further work is needed, and experiments are continuing. Nevertheless, Leon estimated that a new urea finishing process using this technique for large industrial-scale fertilizer application could be launched as soon as the end of 2018.

Advanced scrubbing

In the absence of such an emission-free forming technology, the air from a urea forming process must be scrubbed to remove urea dust and ammonia, and regulations on permissible emissions are steadily tightening. EFMA's 2001 Best Available Techniques booklet specifies 50mg/Nm^3 for both urea and ammonia in outlet air, but in 2011 the UAE specified 30mg/Nm^3, and US state requirements for the new plants which began construction in 2013 were as low as 10mg/Nm^3. Stamicarbon, in partnership with Envirocare, has developed a cost-effective *MicroMist* Venturi scrubbing system as part of a six-step purifier including a concentrated urea quench; a dilute urea quench; (optional) tray conditioning; the Venturi tubes; acid treatment for ammonia capture, and a high efficiency mist eliminator stage with optional wet electrostatic precipitator. The Venturi stage aggregates fine particulate and droplets which can be more easily removed. Pilot testing has confirmed that dust concentrations can be reduced to below 5mg/Nm^3 with the electrostatic precipitator option. ■



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Advanced materials for metal dusting environments

The metal dusting phenomenon is a recurring problem in syngas plants. **Dr Tracey Holmes** of Special Metals Corporation discusses applications where such attack might occur and reports on INCONEL® alloy 693, a nickel-chrome alloy which has demonstrated superior performance under severe metal dusting conditions.

Recent technology advances and concern regarding the long-term viability of reliance upon oil reserves have all acted to prompt interest in alternative fuels. Production of synthetic liquid fuels can now be accomplished using a number of starting stocks primarily natural gas and coal. Other alternatives under consideration include biomass and waste products. Regardless of the starting stock production of syngas for these processes and others results in exposure of components to gas streams capable of causing metal dusting.

Metal dusting is one of the biggest challenges in the cooling of CO-containing process gases and has been responsible for considerable losses in equipment and production time across numerous industries including petrochemical processing where plants producing methanol, ammonia, hydrogen and gas-to-liquids plants can all suffer attack. The phenomenon, termed metal dusting, can be described as a catastrophic form of carburisation which occurs under conditions where the carbon activity of the gaseous atmosphere is greater than one and can result in rapid metal wastage producing pits and grooves as the affected metal disintegrates into a mixture of powdery carbon and metal particles (see Fig. 1).

Consider steam reforming as an example of a process in which metal dusting can occur. The combination of natural gas or methane with steam at high temperature produces a mixture of gases commonly referred to as ‘syngas’ which contains mostly H_2, CO, CO_2, H_2O and some CH_4. The potential for metal dusting is related to the synthesis gas composition, pressure and temperature. If there is a potential for graphite formation by decomposition of CO and the carbon can diffuse into the metal, metal dusting might occur. Several reactions are suggested as being the mechanism for producing the carbon, namely:

Boudouard reaction

$$2CO \rightleftharpoons C + CO_2$$

CO reduction reaction

$$CO + H_2 \rightleftharpoons H_2O + C$$

methane decomposition

$$CH_4 \rightleftharpoons C + 2H_2$$

The Boudouard and CO reduction reactions are carbon producing only below the equilibrium temperature. Methane decomposition is endothermic meaning carbon formation occurs above the equilibrium temperature. Practically this means that there is a critical temperature range between ~400 and 815°C where metal dusting is a concern.

The need for greater efficiency has reduced the quantity of steam used for the reforming process resulting in lower steam-to-hydrogen ratios. Higher front-end pressures have also increased the CO content of the syngas. Lower H_2O/H_2 ratios in

Fig 1: **(Left) Metal dusting on the internal surface of a catalytic reformer furnace tube and (Right) Photomicrograph of metal dusting pit in alloy 600 reformer pigtail connecting ring in service for approximately five years**

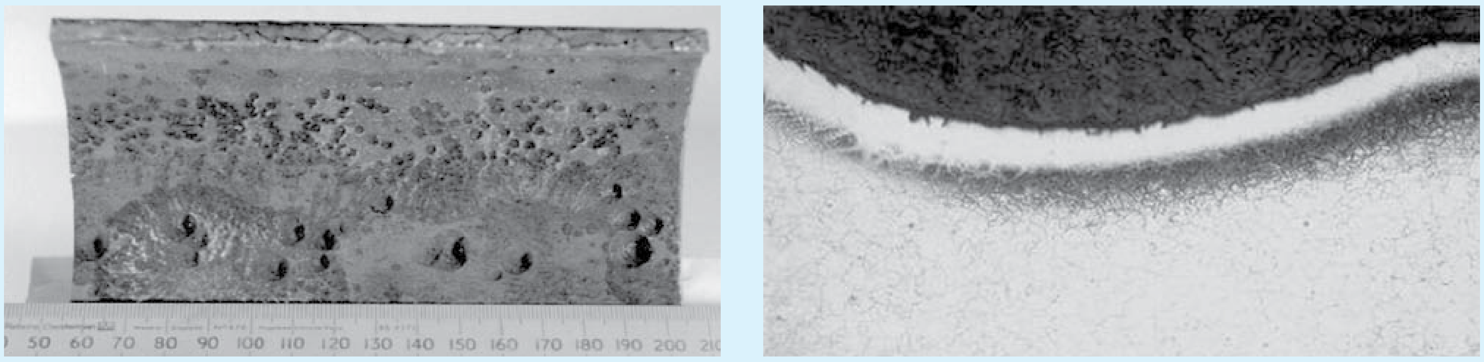

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Table 1: **Nominal chemical compositions (wt-%) for materials presented**

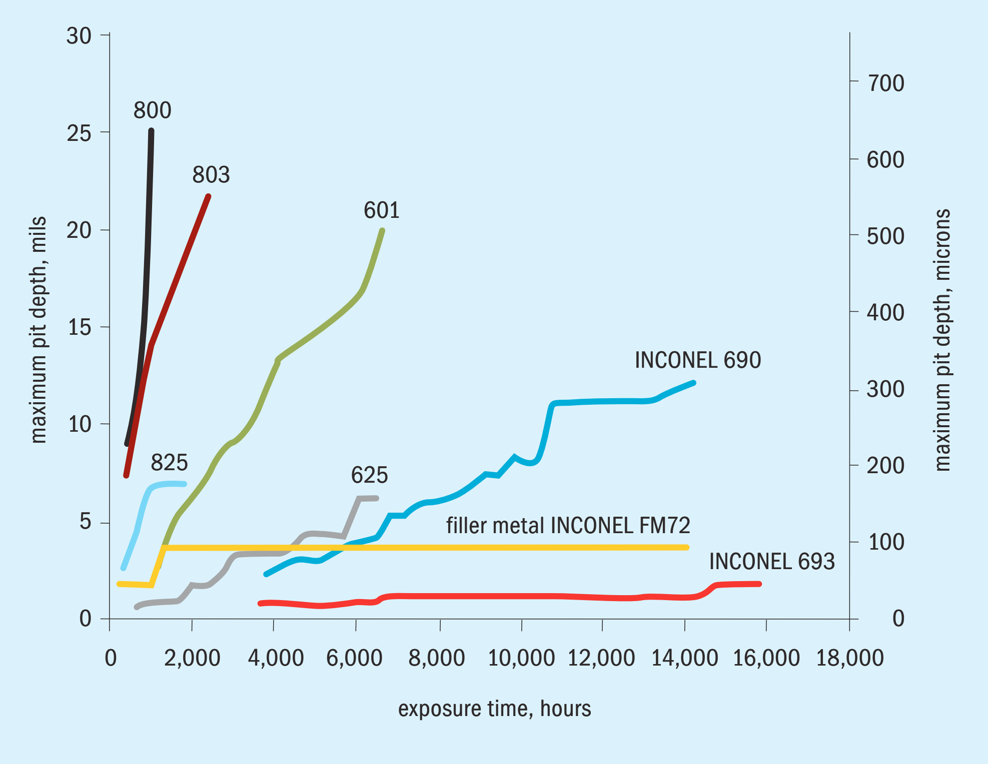
Alloy	Ni	Cr	Fe	Mn	Si	Al	Ti	C	Other
INCOLOY® alloy 800	32	21	45	0.9	0.1	0.4	0.4	0.07	-
INCONEL® alloy 600	72	15.5	8	0.3	0.3	0.3	0.3	0.08	-
INCONEL® alloy 601	60.5	23	13	0.2	0.2	1.4	0.4	0.05	-
INCONEL® alloy 625	61	22	3	0.3	-	0.3	0.2		9 Mo
INCONEL® alloy 690	59	29	9	0.2	0.1	0.3	0.3	0.02	-
INCONEL® alloy 693	62	29	3	-	-	3.3	0.3		0.6Nb
INCONEL® filler 72	55	43	0.3	-	0.1	0.2	0.5	0.02	-
INCOLOY® alloy 803	38	26	36	0.6	0.1	0.5	0.5	0.06	

Note: INCONEL® and INCOLOY® are trademarks of the Special Metals Corporation group of companies

combination with higher CO/CO_2 ratios result in lower oxygen partial pressures and higher carbon activities respectively. When such gas mixtures are present in the process stream in the critical temperature range metal dusting can be a severe corrosion problem for standard materials[1]. The need to maximise the efficiency of steam reforming technology has led to the development of equipment which must be capable of operating within the range of temperature and carbon activity which can promote metal dusting. This necessitates the use of materials which exhibit excellent resistance to metal dusting attack.

The materials subject to gases with a metal dusting potential are protected from attack if a good and stable oxide is formed and continuously maintained as the oxide prevents the diffusion of carbon into the material. Chromium and aluminium are considered to be elements developing impermeable and protective oxide layers. Nickel-chrome alloys promoting chromium oxide and aluminium oxide development in the relevant temperature ranges and atmospheres are expected to perform best. INCONEL® alloys 601 and 693 exhibit beneficial contents of chromium and aluminium, INCONEL® 693 containing 29 wt-% and 3.3 wt-% respectively (see Table 1). Extensive testing coordinated by the Materials Technology Institute in the USA and the TNO Institute of Industrial Technology in Europe confirm the superior metal dusting resistance of INCONEL® alloy 693[2,3].

Fig 2: **Maximum pit depth measurements for samples exposed to CO-20% H_2 at 621°C**



Metal dusting in a laboratory environment

Maximum pit depth as a function of time is plotted in Fig. 2. Testing procedures have been described elsewhere[4] and the carbon activity of the gas has been calculated as 57.9. The plateau in the maximum pit depth measurements for INCONEL® alloys 690 and 693 is evidence of oxide healing behaviour. Based upon these observed pitting rates and mass loss rates in laboratory testing and the results of in situ field exposures INCONEL® alloy 693 shows excellent metal dusting resistance by forming a thin adherent oxide film and offers the most promising performance to end users seeking metal dusting-resistant materials.

Field performance

The photomicrograph in Fig. 1 shows metal dusting attack of alloy 600 piping from a reformer pigtail. The reformer had been in service for approximately five years. Alloy 601 has been used as an upgrade for waste heat boiler shells and tubing in ammonia plants as well as for reformer components and has resulted in greater production due to decreases in downtime and repair costs. Recent advanced designs and harsher service conditions necessitate the use of materials which possess performance capabilities beyond those of alloy 601. INCONEL® alloys 690 and 693 offer that capability.

Industrial experience

The Haldor Topsoe Exchanger Reformer (HTER) is a proven technology and has been in successful commercial operation since early 2003 in a synthesis gas plant

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Ferrules for syngas service fabricated from INCONEL® alloy 693.

Installation of HTER internals, comprising INCONEL® 693 double tubes, at the Sasol Synfuels facility in Secunda, SA[6].

in South Africa with great success. The HTER installed was of the double-tube type and by applying this technology the syngas production from the plant was increased by more than 30%[6]. The technology has since been expanded and adapted for use in both syngas and ammonia processing applications. A major challenge in connection with the HTER heated by reformed process gas is corrosion by metal dusting.

Typical conditions in the reformer and equilibrium temperatures for carbon-forming reactions in different plant types (Table 2) show that the process gas passes through the metal dusting critical temperature range and so there is potential for this mechanism of attack. Special Metals alloy INCONEL® 693 has a long incubation time and low corrosion rate which is why it has been utilised to great effect in the HTER design enabling the increased efficiency and output[7,8].

Welding

Fabrication of most equipment and components require some degree of welding and the weld can be the most vulnerable area to metal dusting attack. In applications where corrosion resistance is as important as strength a matching welding consumable or weld overlay should be considered. The filler metals FM72 and 53MD have been developed as complementary compositions to the highly resistant INCONEL® alloy 693. In applications requiring higher strength and stability a welding consumable selected for its mechanical properties can be capped with a more corrosion resistant consumable. Combined weldments using FM52 capped with FM72 or FM53MD have been used to provide an optimum combination of strength, stability and corrosion resistance.

Table 2: **Typical conditions for the main reformer and equilibrium temperatures for carbon forming reactions in different plant types[8,9]**

	H_2 plant	**NH_3 plant**	**ATR-based**
Steam to carbon ratio	1.8-2.5	2.5-3.6	0.6-1.5
Outlet temperature, °C	850-930	950-1,000	1,000-1,050
H_2/CO ratio	3.3-4.5	~4	~2
Boudouard reaction, T_{eq} °C	770-800	790-820	800-830
CO reduction, T_{eq} °C	750-780	750-780	770-800
Methane decomposition, T_{eq} °C	>950	>1,200	>1,100

Conclusions

Due to efforts to increase the efficiency of processes involving the production of syngas and development of advanced catalysts metal dusting corrosion has become more prevalent. Failures of iron-base alloys as well as nickel-base alloys which contain insufficient levels of key alloying elements have prompted equipment designers to seek materials that are more resistant to metal dusting. Field and laboratory data confirm the desirability of addition of certain scale-forming and possibly carbide-forming elements in conjunction with a nickel-base alloy matrix to limit pit progression rates. INCONEL® alloy 693 offers a combination of properties which make it an attractive choice for resistance to harshly corrosive high temperature environments, particularly those conditions which promote metal dusting. The material has been shown to be readily weldable and to exhibit desirable engineering properties in addition to its excellent corrosion properties. INCONEL® alloy 693 has been successfully employed under severe metal dusting conditions in many applications; being used for heat exchanger tubing and baffle plates, for thermocouple protection tubes, ferrules, burner nozzles and syngas bypass duct linings. ■

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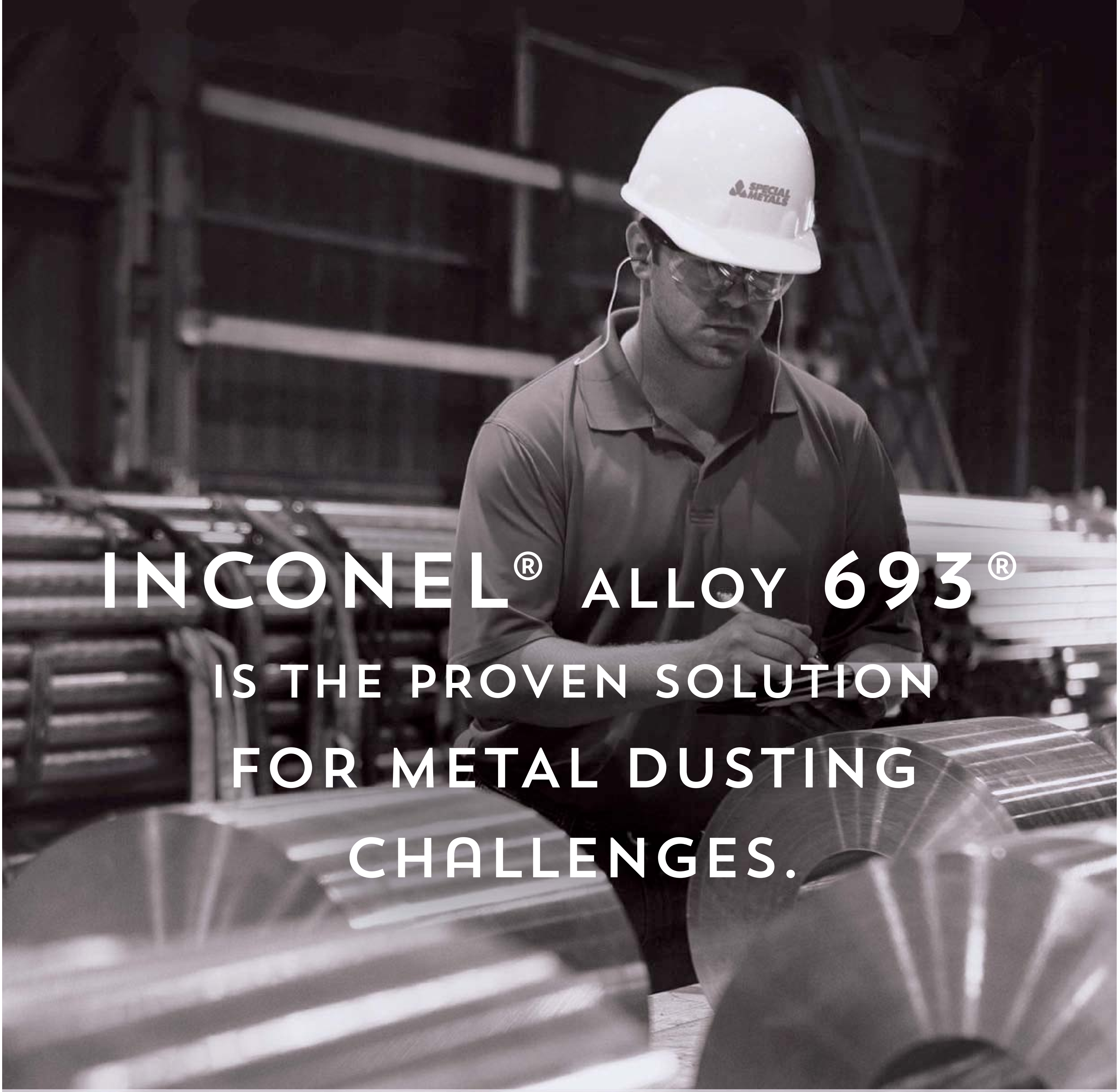
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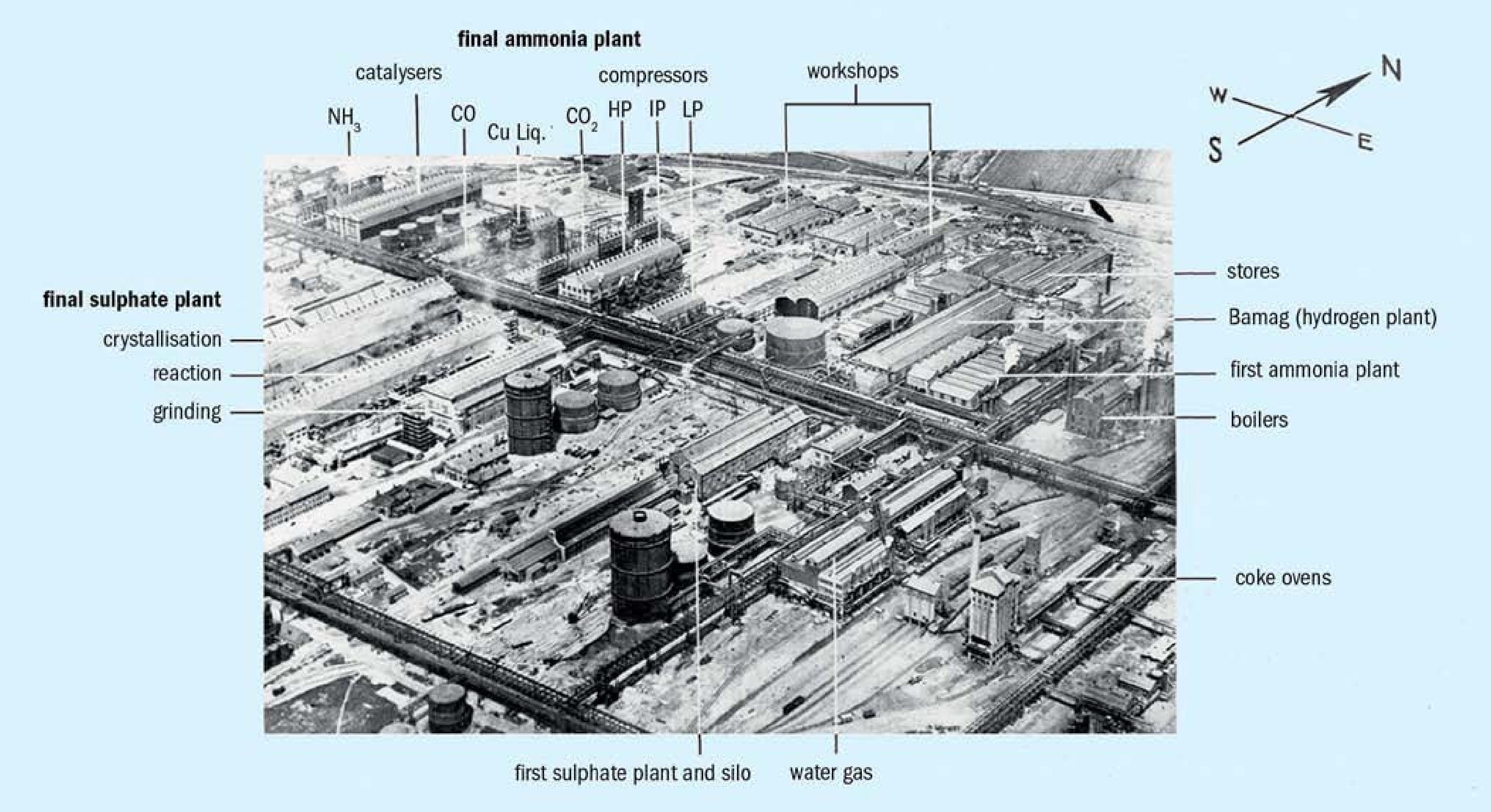
Developments in ammonia plant safety

In the 1920s ammonia production commenced at Billingham in the UK at a site then owned by Brunner Mond which later became part of ICI. Today Billingham site remains active in syngas and ammonia production via Johnson Matthey Process Technologies and through CF Industries UK Ltd fertilizer business. In common with operators of ammonia technology globally, the Billingham complex has always had a strong interest in making the industry safer and more reliable as **John Brightling** of Johnson Matthey relates.

Fig 1: **Layout of ammonia and sulphate plants, Billingham, 1930**



This article reviews the history of ammonia plant safety at Billingham and how it influenced, and was influenced by the wider industry and outlines some key incidents and advancements over the years as technology and approach to safety developed.

The early years

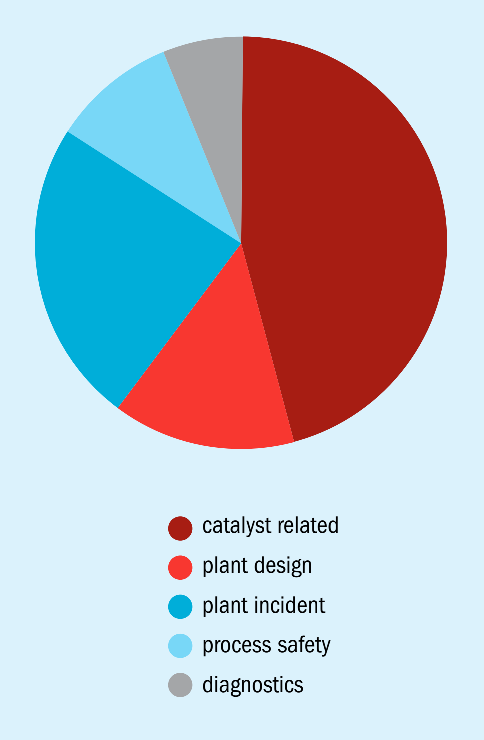
Ammonia production was first established at Billingham on 24th December 1923, based on the original Haber-Bosch process[1]. In this process, coke was generated then contacted with steam and air to make syngas, which was then purified via a number of stages before compression to 250 bar before introduction into the ammonia synthesis loop.

Additional capacity based on similar technology was added to the site over the years, made on a number of low pressure production trains spread over a huge area. However, production based on coke was excessively expensive as cyclic water-gas processes were fundamentally inefficient. Theoretical usage of coke is 0.9 tonnes per tonne of ammonia, whereas the actual use at that time was more than double this, and the plant required was heavy, voluminous and had high maintenance costs[2].

Regrettably, the first fatal accident to occur at the site took place in April 1924, shortly after the start of operations. The incident was the result of a non-return valve failing and allowing gas at high pressure to pass backwards through a pump, into a low pressure gas line.

A report, which describes the accidents which occurred in the Billingham factory between 1924 and 1928, makes sad reading because the accidents seem inevitable given the operating standards in existence.

Fig 2: **Breakdown of the types of incidents presented in AIChE safety papers from Billingham businesses**



There were several serious accidents in which men were killed because they broke into pipelines which had not been properly isolated.

On 18 January 1928 a fatal accident occurred at the Billingham site. A 36 inch diameter gas main was being modified and a number of joints had been broken, the line was isolated from a gas-holder by a closed isolation valve. This valve leaked and allowed gas to diffuse through the whole length of the main. The gas ignited, there was a loud explosion and flames appeared at various joints on the main. One man was killed. The source of ignition was a match struck by one of the workmen so that he could see what he was doing! The conclusions of the original report were:

- Never trust an open gas main attached to a system containing gas, and keep all naked lights clear.
- When working on pipe bridges at night, adequate lighting should be available.
- Never place absolute reliance on a valve, a slip-plate is easy to insert and absolutely reliable.[3]

It is clear from the recommendations that the ‘lessons learned’ include the birth of operational standards which remain present in the industry today – equipment which is handed to maintenance must be isolated by slip-plates; do not rely on valves which may leak.

The men who were injured and the men who wrote the reports have long since died and the plants have long been demolished, but the messages in the reports are as true as on the day they were written.

Plants based on coke ovens tended to have a low reliability, so were maintenance heavy and therefore needed a large workforce. By the end of the 1950s a workforce of many thousands of people at Billingham was responsible for making an output of ~750 t/d, relatively modest in today’s terms, on a number of small ammonia units. The first major change to improve syngas production efficiency was the use of partial oxidation, as developed in the 1950s. At Billingham a gasifier was built for heavy fuel oil feed, this generated syngas at 30 bar, requiring an oxygen feed from an air separation plant[2].

Air separation plants have high risks associated with them, as enriched oxygen streams carry a heightened risk of fires and explosions if there is any loss of containment or build-up of flammable hydrocarbons in the stream. Frequent explosions in these air separation units compelled a dedicated group of engineers to meet and share incidents and research on how plants could be run more safely. The first Ammonia Safety Symposium was held in 1956 as a part of the Boston, Massachusetts AIChE National Meeting where papers were presented and an “oxygen safety conference” was held. Since then the AIChE Ammonia Safety Symposium has been held annually with little change in its format. That it still functions today is a tribute to its effectiveness in reporting accidents, safety developments and other technical improvements relating to safety to the international community of fertilizer producers, suppliers, and designers.

Sharing safety information across the industry

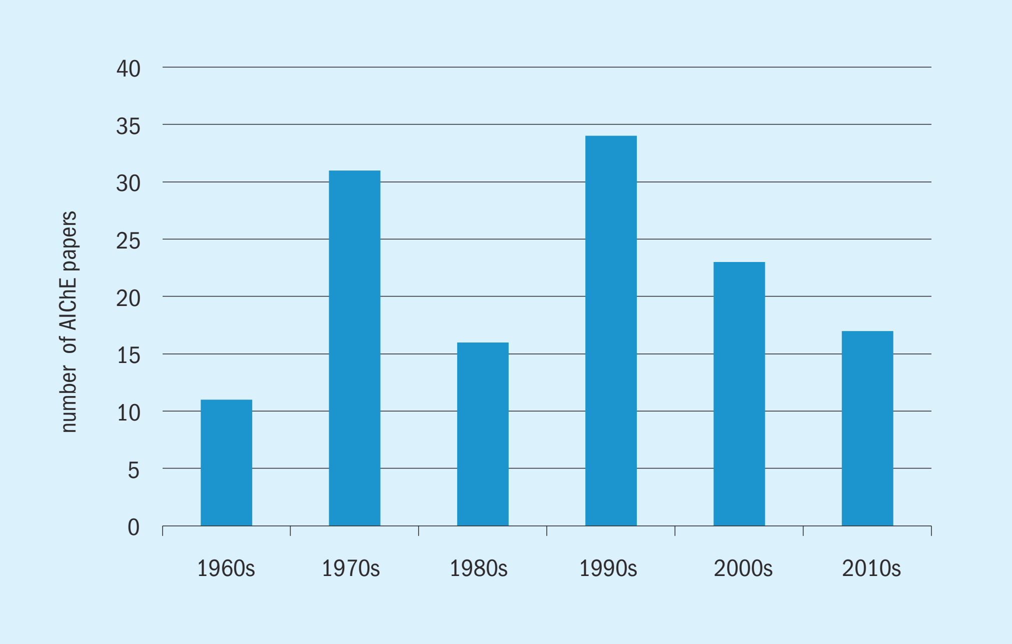
In the 60 years it has been running, there have been more than 1,500 papers presented at the AIChE Ammonia Safety Symposium and untold lives have been saved, injuries prevented and property saved as a result of this sharing that takes place at these symposia. Since its first involvement in 1960 there have been around 130 papers originating from the operating experiences, process and catalyst knowledge from the businesses based at Billingham site with interests in ammonia safety – a breakdown of the core themes of these is presented in Fig. 2.

Since the first contribution to the meeting in 1960 there have been regular papers presented by businesses associated with Billingham (see Fig. 3).

The first contribution from Billingham to the AIChE meeting was in 1960 and described an accident on a 240 t/d oxygen plant on 21st April 1959, in which without warning one corner of the coldbox was wrecked by an extremely violent explosion, killing three men.

The accident was intensively investigated by a team of chemists and engineers from ICI and Air Products and the investigation concluded that the explosion had

Fig 3: **Number of papers contributed to AIChE Ammonia Safety Symposium from Billingham**



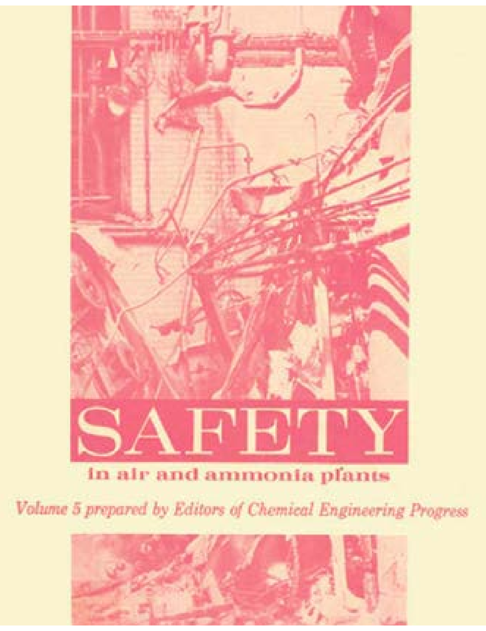

SAFETY
in air and ammonia plants
Volume 5 prepared by Editors of Chemical Engineering Progress

Fig. 4: Cover of Safety in Air and Ammonia Plants Vol 5, Denver, USA 1962.


Fig. 5: Three 1,000 t/d Kellogg plants built at Billingham.

been caused by hydrocarbon oil from the lubricating system of the turbo-expanders reaching leaking oxygen from pipe joints in the cold box. In light of the growing knowledge of the hazards a critical reappraisal of all aspects of process and engineering design was initiated, looking at any deviations that could be regarded as being potentially hazardous[4].

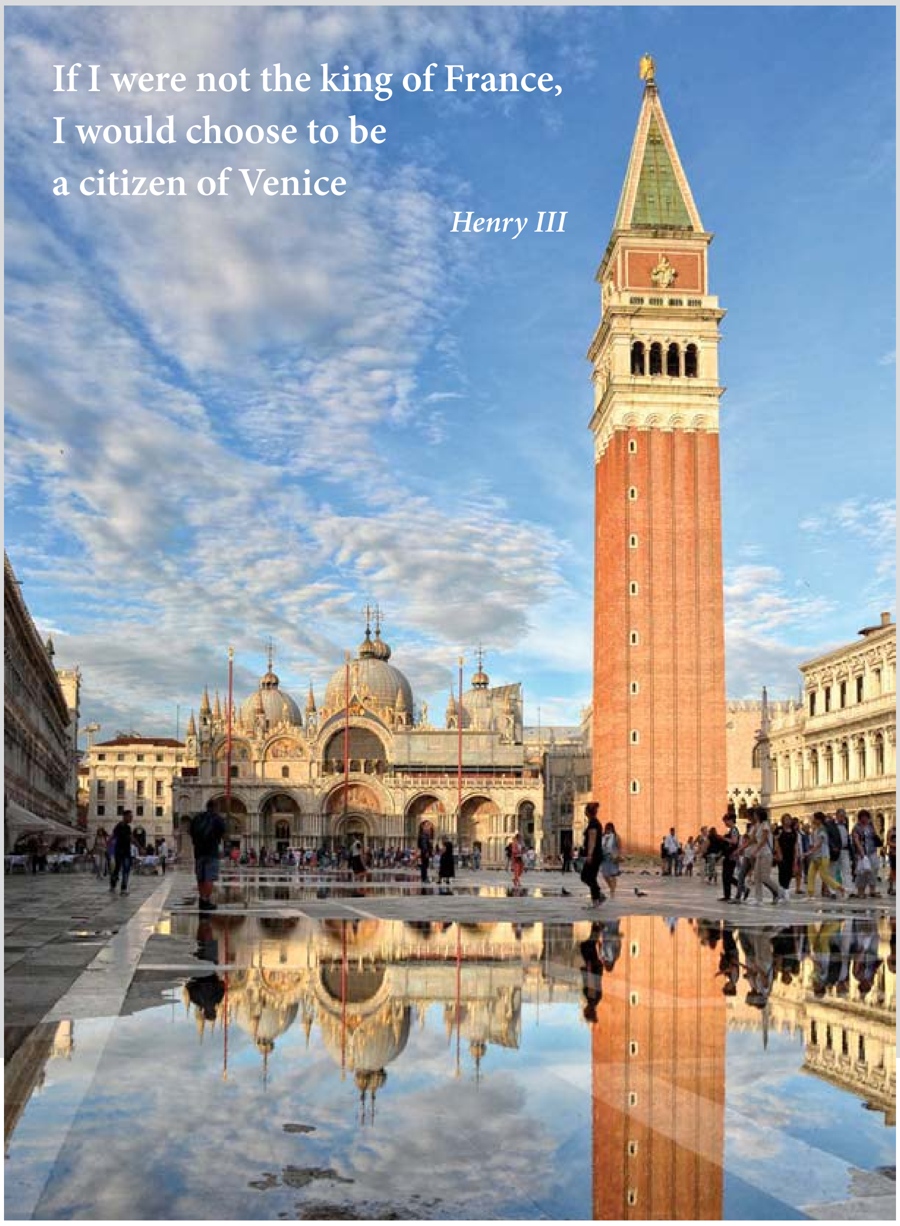
Findings from the investigation were presented in a paper at the 1962 AIChE Meeting in Denver, USA, with a photograph from the incident on the cover (Fig. 4).

With the investigation conclusions referring to a critical reappraisal of all aspects of process and engineering design this set the tone for a safety study practice that was under development at that time with a technique called critical examination which asked for alternatives (deviations) – the method was later refined within the company, under the name operability studies.

Even without the higher risks, costs of syngas production by the partial oxidation route were relatively high and soon found to be uneconomic compared to steam reforming, for which developments were made at Billingham. By the mid 1960s steam reforming processes were integral to modern single stream plants, with three new 1000 t/d Kellogg plants built at Billingham (Fig. 5). These plants produced over 1.5 times more ammonia on a smaller footprint, occupying 15 acres rather than 51, and the man-hours per tonne of ammonia were reduced from 12 to 0.3.

However, this single stream technology brought with it new challenges. In 1968 ICI's KATALCO™ presented a paper, "Catalyst safety in large ammonia plants", summarising the increased hazards that came with larger catalyst inventories and the need for proper procedures to manage the issues experienced. In terms of specific technological issues, there was a need to share operating experience on how to deal with these new assets[5]. In 1969 at the AIChE meeting

Fig. 6: Stills from "Catalyst Discharge from a Kellogg Ammonia Converter" *, ICI, Billingham, 1969.*



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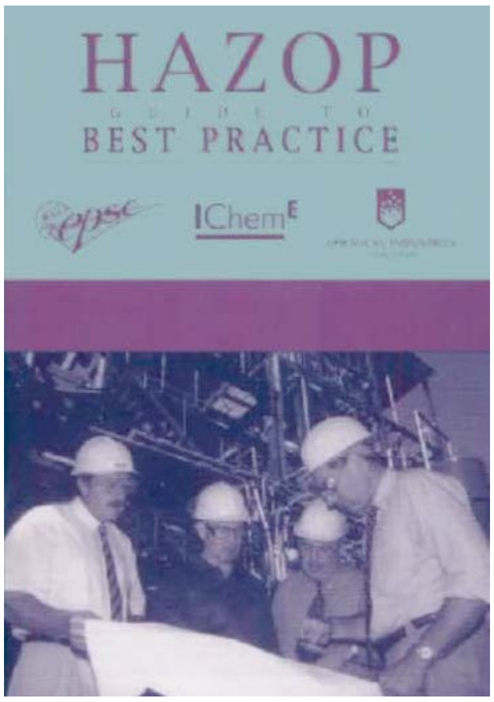

Fig. 7: Cover of HAZOP Guide to Best Practice.[7]

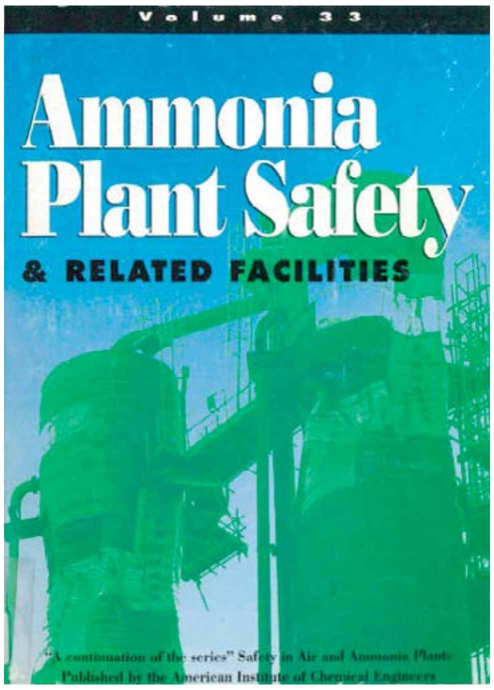

Fig. 8: Image of vacuum damage to CO_2 towers, Vol 33, San Antonio, Texas (1992).

in Portland, ICI Billingham showed a film "Catalyst discharge from a Kellogg ammonia converter" of how, following an internal failure in the converter, they had to change the KATALCO 35-4 ammonia synthesis catalyst in the new converter 'bottle' designs'. Fig. 6 shows stills of the film.

The benefits of open communications for sharing experience were confirmed the following year by Donald F DeLong, VP Manufacturing, CF Industries Inc., in a paper[6] describing how internal damage to an ammonia converter in their Donaldsonville plant required the catalyst be safely discharged and replaced with the credit "motion pictures of the synthesis catalyst removal shown by ICI Billingham during the 1969 Ammonia Safety Symposium were of great benefit in making plans for catalyst removal".

Development of hazard studies

In 1974 at Flixborough, UK, a cyclohexane vapour cloud explosion in a caprolactam plant killed 28 people on site and damaged 2,000 properties. The poor design of a 20 inch pipe installed as a temporary modification was identified as the main cause. This incident showed that the industry was clearly in need of methodologies for hazard assessment, to minimise the risks of further incidents.

As previously mentioned, engineers at Billingham had developed procedures to improve the safety of new plants with a technique called critical examination for deviations. Soon after the Flixbrough incident the procedure was donated to the chemical industry, with the first HAZOP course being held at the local Teesside University in 1974 – a key process risk assessment tool used worldwide today (Fig. 7). Before its introduction, safe operation was often learned the hard way: by experiencing fires, explosions and toxic releases, and learning how to prevent them. The breakthrough was the recognition that the answer to preventing process accidents lay in the hands of the designer – by critically examining and questioning the design in detail, plants could be made safer.

Another company procedure, issued in 1972, required the use of quantified risk assessment techniques both to confirm the adequacy of trip systems and to calculate the frequency with which they needed to be proof tested in order to maintain their integrity, similar to SIL ratings and LOPA analyses[8].

In October 1983 an incident caused the collapse of the top sections of both CO_2 regenerator towers on one of the Kellogg ammonia plants, due to the formation of an internal vacuum. The vacuum was created by the regenerators cooling and steam condensing in the vapour space whilst the towers were isolated from vent lines. The conditions for vacuum formation were established as a result of abnormal operating conditions and actions, and were maintained due to failure and inadequacy of a nitrogen blanket protection system and operating procedures[9]. An image from the failure was later used as another cover image for a future set of the AIChE Conference proceedings (Fig. 8).

Learning lessons from the past

Explosions and fires can be major incidents in ammonia plants, even within the areas of the plant that are typically considered less dangerous. Atmospheric pressure tanks containing an aqueous solution of ammonia could be considered as a low risk area, however an explosion of a weak aqueous ammonia solution tank occurred in January 1973 at Billingham (Fig. 9)[10]. As a result, 1,000 tonnes of solution escaped as the bund wall was demolished in the incident and four people were affected by ammonia fumes as it spread over the surrounding area.

An investigation concluded that the tank failed because of the combustion of gases in the vapour space of the tank, the source of ignition, however, could not be identified and therefore a new code of practice was introduced to cover all likely possibilities. These safeguards included the mandatory use of a nitrogen gas blanket where hydrogen can accumulate, fully earthing the tank to eliminate potential for ignition from static charge, and any associated electrical equipment being designed as intrinsically safe so that it is not capable of initiating an explosion.

In October 2009 an explosion occurred at a European plant on an atmospheric aqueous ammonia storage tank collecting solution from purge scrubbers (Fig. 10).[11] The explosion was due to the combustion of an air/hydrogen mixture, with the most likely scenario being that the explosive mixture ignited due to a lightning strike. Key learning from the investigation was that hydrogen/air could accumulate and reach explosive limits and this needs to be addressed through process design either by removing the risk of explosive accumulation (e.g. nitrogen purge) or designing the systems so that all possible ignition sources are eliminated with the applicable hazardous area classification code. This demonstrates the importance of taking heed of past incidents and effectively communicating risks and learning in this regard across the industry.

Conclusion – taking the learnings forward...

Brunner Mond attached great importance to safety and employee conditions, the company's policies were far ahead of the industry as a whole and they became the policies of ICI. Process safety became

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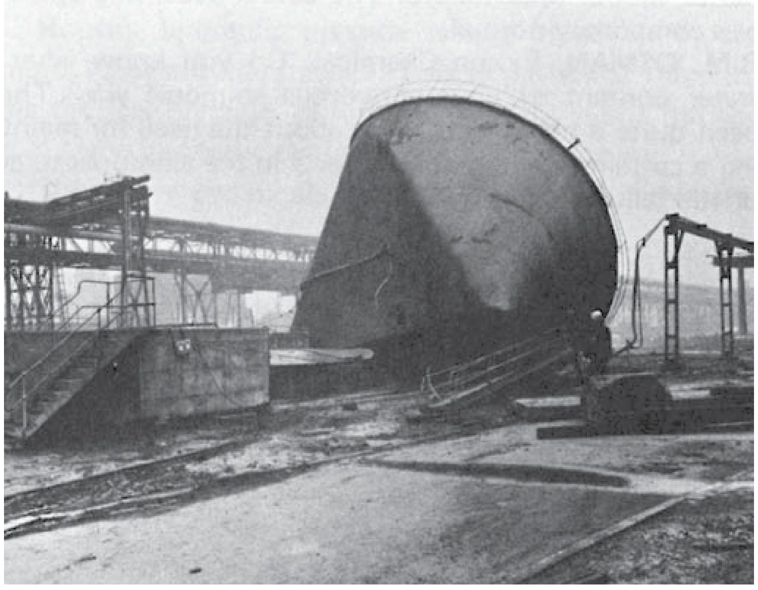

Fig. 9: Ruptured aqueous ammonia storage tank, Billingham, 1973.

Fig. 10: Ruptured aqueous ammonia storage tank, Europe, 2009.

Table 1: **AIChE Symposium ammonia incident review papers by Johnson Matthey**

Year	Meeting	Title
2016	Denver	EHS, technology and product risk assessments for the nitrogen industry
2016	Denver	Catalyst reactive hazard assessments in ammonia flowsheets
2013	Frankfurt	NH_3 production – Century of safety, health & environmental improvements
2011	Montreal	What not to do on your plant (Catalyst catastrophes III)
2011	Montreal	Process safety in the fertilizer industry, a new focus
2010	San Francisco	Lessons learnt with ammonia synthesis
2005	Toronto	Catalyst catastrophes II
2004	Denver	Common problems on steam reformers
2003	Orlando	Catalyst catastrophes

a recognised discipline within ICI with practitioners such as Trevor Kletz, who started work at Billingham in 1944, remaining with the company to the 1980s. Over that period many major innovations in process safety were made by the company, including: hazard and operability studies (HAZOP), quantitative risk assessment (QRA) (also known as hazard analysis or HAZAN), inherently safer design, management of change, causes of accidents, including human factors and improving the preparation of equipment for maintenance, all of them were published and made freely available to the process industry as a whole. In addition, there were systematic attempts to remember the lessons of the past where the actions included widespread circulation of accident reports both inside and outside the company, recycling of information, as well as regular discussion of recent and past accidents.[12]

To help keep relevant learning and experience alive within new generations of staff operating plants, in recent years Johnson Matthey has continued this approach taking a leading role in preparing inputs for the AIChE Ammonia symposium, analysing relevant incidents from the past and the lessons learnt.

The symposium has prevented many similar incidents from happening, due to people being aware of what has happened elsewhere. Through the papers presented at these symposia we have been able to make our industry safer and more efficient. Knowledge of past experiences has helped others to pre-empt and avoid incidents and bad practices, while building on positive experiences and design improvements to make a more efficient industry. This year, Johnson Matthey is presenting two papers at the symposium, continuing the tradition of supporting safety within the ammonia industry.[11]

These papers along with other recent papers presented at the symposium sharing learning from past incidents are listed in Table 1. ■

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Reformer furnace revamps

A selection of case studies of major reformer furnace revamps by Casale illustrate how syngas plants can be revamped for increased plant capacity, reliability and efficiency and a new improved reformer tunnel system development by Blasch Precision Ceramics provides improved flue gas flow uniformity and potentially better catalyst tube reliability.

Catalytic steam reforming of hydrocarbons in tubular reformers is the most common process for the production of synthesis gas and the steam methane reformer is widely accepted as being the most complex and energy intensive part of any ammonia, methanol or hydrogen plant. Being at the heart of ammonia plants, the primary reformer has a strong impact on the overall plant performance and it is important that is operating and maintained under the best possible conditions in order to achieve peak performance.

Revamping steam reformers can provide a cost effective way to improve plant efficiency, increase plant capacity and improve reliability.

Casale reformer revamps

Casale is gaining more and more experience in the revamping of these furnaces. Several examples of modifications carried out by Casale on different type of reformers are presented in the following cases:

Case 1:
Revamp to increase plant efficiency

The first example describes a revamp that was carried out to make energy savings and provide a slight capacity increase.

Different modifications can be implemented to improve the energy efficiency of an ammonia plant, these modifications are centred on reducing the natural gas specific consumption, the steam import from the utilities or the electrical consumption.

In this plant the modifications were specifically focused on those sections where changes could provide significant energy saving with a reasonable capital cost.

The main plant limitations both for capacity increase and energy saving were:

- high primary reformer stack temperature;
- high CO_2 removal section specific consumption;
- machines close to their limits;
- synthesis loop overloaded;
- low MP steam header operating pressure.

In order to overcome these limitations Casale made the following changes:

- installation of a new saturation section;
- minor revamp of the air compressor;
- revamp of the CO_2 removal section;
- revamp of the synthesis gas compressor LP body;
- installation of a new additional ammonia converter bed;
- replacement of the refrigerant compressor turbine.

The existing primary reformer is a Foster Wheeler terrace wall furnace and the flue gas temperature at the stack was quite high and close to 300°C.

The installation of an air pre-heating system was immediately ruled out due to the structural impact that this could have on the existing primary reformer, moreover an air pre-heating system is quite bulky and its installation at 20-25 m elevation, as last coil of a terrace wall primary reformer, was too risky.

It was decided to design a new saturation tower (Fig. 1), provided with a new coil installed in the top part of the primary reformer, to recover the heat available in the flue gas.

Installation of this coil required the primary reformer roof and the relevant ID fans to be elevated by 1 m as the available room was not enough for the required new coil.


PHOTO: CASALE

Fig 1: Installation of new saturation tower.

The process condensate stream fed to the saturation coil was taken directly by a new pump from the KO drum located upstream of the CO_2 absorber, and routed, after pre-heating, to the new coil.

The desulphurised natural gas is first cooled in a saturator feed/effluent exchanger and then fed to the new saturator tower, where it is countercurrently washed by the pre-heated process condensate.

The steam to carbon ratio downstream of the saturator is about 0.5-0.55 mol/mol, providing MP steam saving in the steam system.

The new scheme allowed a reduction of the stack temperature to 190-195°C and the relevant energy saving was about 0.15-0.2 Gcal/t.

Case 2:
Revamp to increase plant capacity

The modification implemented in this revamp was for a capacity increase, where a purifier plant was transformed into a conventional ammonia plant.

The primary reformer was an original Foster Wheeler design side-fired reformer. The tubes were at their end-of-life and the frequent failures were causing severe plant reliability issues. The major changes carried out were:

- tube arrangement changed from staggered to inline;
- number of tubes increased;
- extension of the radiant box;
- installation of additional burners;
- replacement of the old burner tips;
- replacement of the mixed feed coil.

The radiant box extension was shipped in sections with insulation pre-installed, ready for assembly. In addition, a pre-reformer with dedicated heater was installed.

The composition of the fuel gas to the burners was changed with the elimination of waste gas from the purifier section. The gas from the hydrogen recovery unit was subsequently much less and the burner tips were changed as a result. The gas turbine exhaust, which supplies oxygen to the burners, was deemed to be insufficient and an auxiliary air blower was installed to supplement the oxygen supply. The exhaust of this blower was tied into the gas turbine exhaust ducting.

Fig. 2 shows the pre-reformer arrangement with new items shown in red.

Case 3: Revamp for improved reliability

The existing primary reformer in this case was a Foster Wheeler design, terrace wall type, with 120 catalytic tubes, 60 in each cell. The convection section has process steam, process air, high pressure steam (100 bar) super heater and boiler feed water coils. The revamp included changes to the convection section, burners and catalytic tubes.

The modification to the convection section consisted of replacing the process steam heater coil due to its age and limitation in design temperatures (Fig. 3).

The burners were replaced due to their poor performance. Naphtha as fuel was no longer used.

The new burners can operate with natural gas, or a mixture of natural gas and off-gas, in case this fuel becomes available to the plant in the future.

The new burners are John Zink burners. There are 120 burners and 10 auxiliary burners. The burners are GO-SFG-M type, the maximum heat released to these burners is 0.95 MMkcal/h and the maximum capacity pressure is 0.8 bar. The auxiliary burners are PVYD-12-RM type, the maximum heat released is 0.625 MMkcal/h and the maximum capacity pressure is 1.5 bar.

The catalytic tubes that were operating before the revamp were Villares "LRE9" with 140 mm external diameter, 16 mm thickness and a lifetime of 65.000 operating hours. The tubes were replaced with Manaurite "XM", from Manoir, with 141,5 mm external diameter and 9.5 mm thickness, which have an expected lifetime of 100,000 hours. Before the revamp, the average wall temperature was 950°C which decreased to 880°C after the revamp.

Case 4:
Revamp to increase plant efficiency

In this case saturator coils were installed in a MWK furnace in order to increase plant efficiency.

In the revamped plant desulphurised gas is fed directly to the new saturator column where the gas is placed in contact with hot process condensate in order to increase its water content.

The saturator column is divided into two sections: the bottom part acts as a stripper and mainly reduces the ammonia/methanol content in the process condensate leaving the column; the top part completes the natural gas saturation by means of heat recovery in the convective section of the primary reformer.

The process condensate coming from main gas separator is preheated and sent to the saturator coil where it reaches the optimum temperature before entering the top of the saturator.

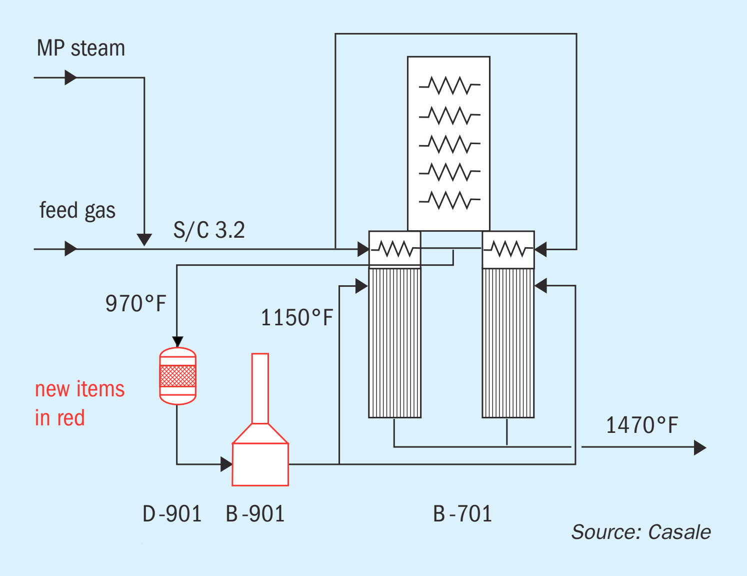
The feed gas is fed at the bottom of the column and passes up the column, increasing its water content thanks to the heat received by the hot circulating water in the reformer coil.

The saturated gas, at about 205°C and with a S/C ratio of about 1.0, is further heated in the saturated gas coil at about 360°C with a pressure of about 36 kg/cm^2g.

The saturator is equipped with a bypass designed for the full capacity that allows the plant to run at reduced capacity in the case of a saturator shutdown.

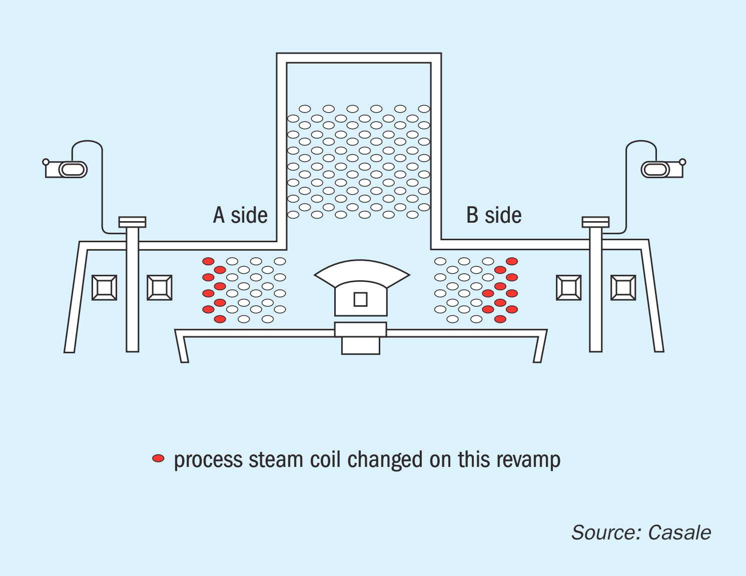
The bottom condensate from the saturator is partially vaporised. The produced LP steam is separated and the overhead

Fig 2: **Pre-reformer arrangement**



Source: Casale

Fig 3: **Modification to steam coils of primary reformer**



Source: Casale

LP steam is sent to the header while the bottom condensate is cooled and sent to off-site treatment.

The reformer furnace is modified to attain maximum thermal efficiency by recovering heat from the flue gases withdrawn from the reformer radiant section.

New coils were provided for the preheating of saturated gas coming from process gas saturator column and for the heating of the saturator circulating water. The hot BFW preheater coil was substituted in the same revamp.

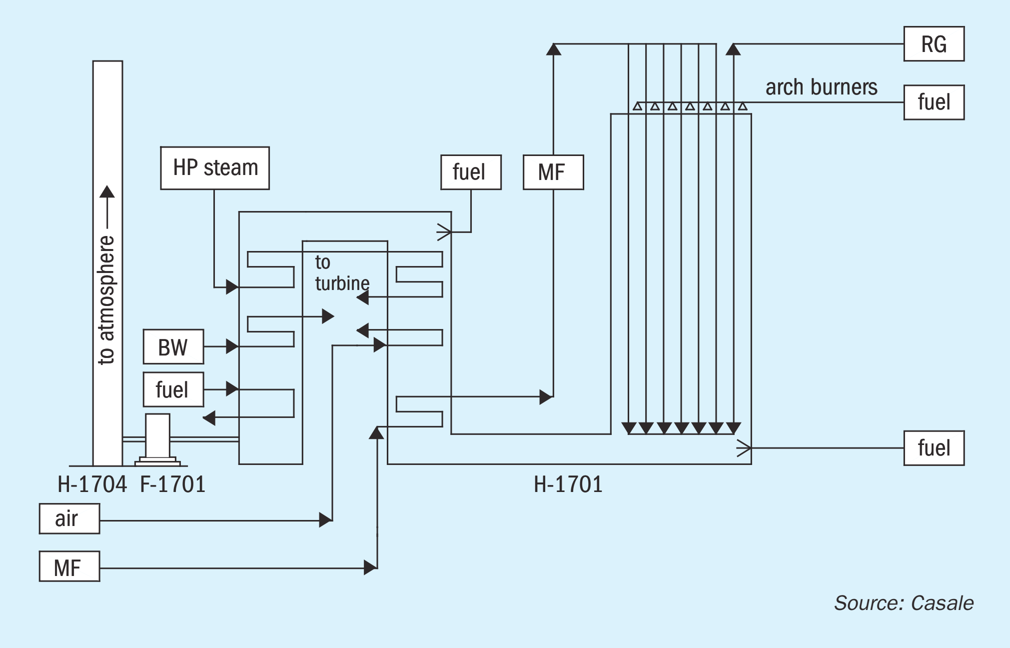
After the modification, the stack temperature was reduced from 237°C (86.7% fuel efficiency) to 200°C (88.1% fuel efficiency).

Case 5: Transforming a GIAP ammonia reformer into a methanol reformer

A Russian client asked Casale to study the possibility to transform one of its GIAP AM 76 ammonia plants into a methanol plant while keeping the same production capacity using as much of the equipment present in its warehouse, originally designed for a new ammonia plant.

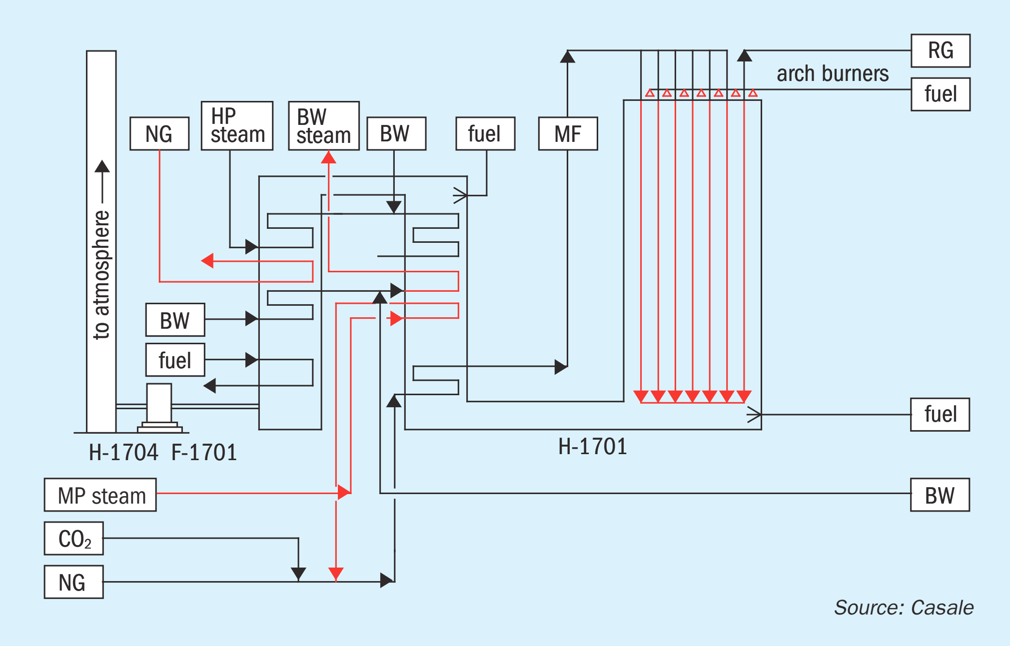
A new methanol plant with a capacity of 1,350 t/d was designed by Casale taking into account the client's requirements not only to maximise the use of the equipment present at the site, but also to maximise the use of new equipment manufactured within the CIS countries under the supervision and responsibility of Casale.

Fig 4: **Existing reformer process scheme**



Source: Casale

Fig 5: **Retrofitted reformer process scheme**



Source: Casale

The process scheme of the GIAP ammonia reformer is very similar to a Kellogg design and is detailed in Fig. 4 together with the convection section.

In order to reach the guaranteed 1,360 t/d methanol capacity, the new reformer configuration required the process design modifications as indicated in Fig. 5.

The main features of the revamp were to:

- increase reforming catalyst quantity from 20.8 m³ to 37.6 m³ by changing catalyst tubes;
- increase radiant heat liberation from 170,000,000 kcal/h to 227,000,000 kcal/h by modification of the roof burners;
- addition of one BFW heater/boiler convection coil;
- addition of one natural gas preheater convection coil;
- utilisation of existing air preheater convection coil to heat MP process steam;
- addition of in-line desuperheater between 1st and 2nd stage HP steam superheaters to control the temperature at the HP turbine inlet.

In the end the client decided not to transform the existing ammonia plant but to build a new methanol plant.

Case 6: Revamp for better reliability and capacity increase

In this revamp the combustion air preheater and mixed feed coil were replaced in a horizontal convection section for reliability and capacity improvement.

The bottleneck at this plant was the front-end section that didn't generate enough reforming gas to produce 3,000 t/d methanol. A contract was signed to revamp the front-end section. The two main goals of the revamp were:

- eliminate the bottleneck to produce the quantity of reforming gas required;
- replace the equipment that had deteriorated.

As part of the revamp of the front-end section, the rotary combustion air preheaters were replaced with plate heat-exchangers. Poor operation of the rotary combustion air preheaters due to big air cross-flows in the steam manifold limited the reformer loading.

To optimise the energy balance, feedstock preheaters coils and BFW preheaters have been replaced, and a new heat-exchanger added for heating the fuel purge gas coming from the synthesis loop.

The front-end section was revamped during the overhaul in 2006.

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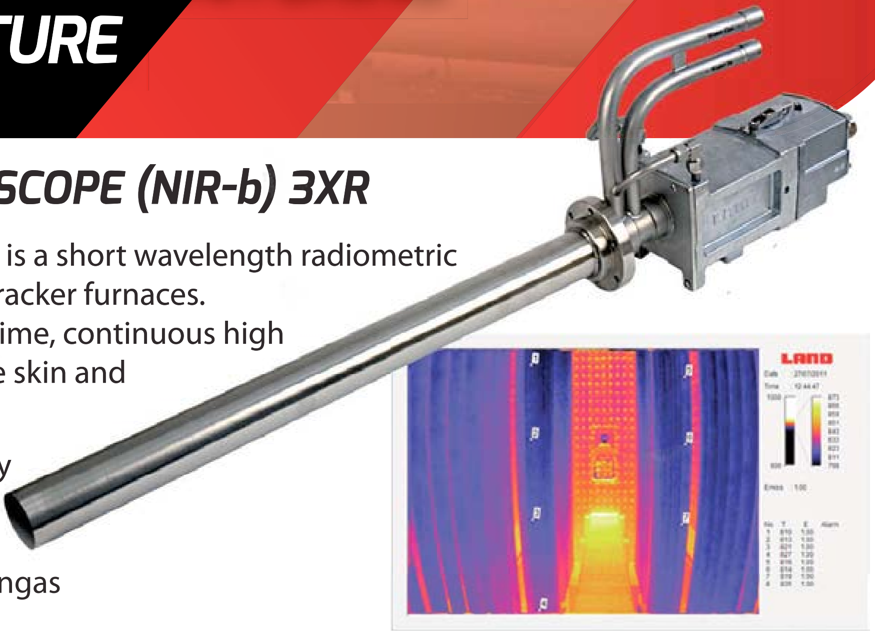

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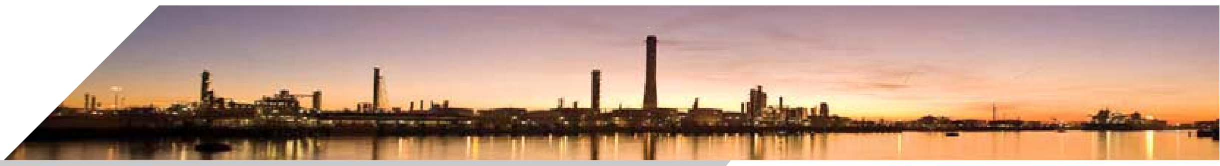

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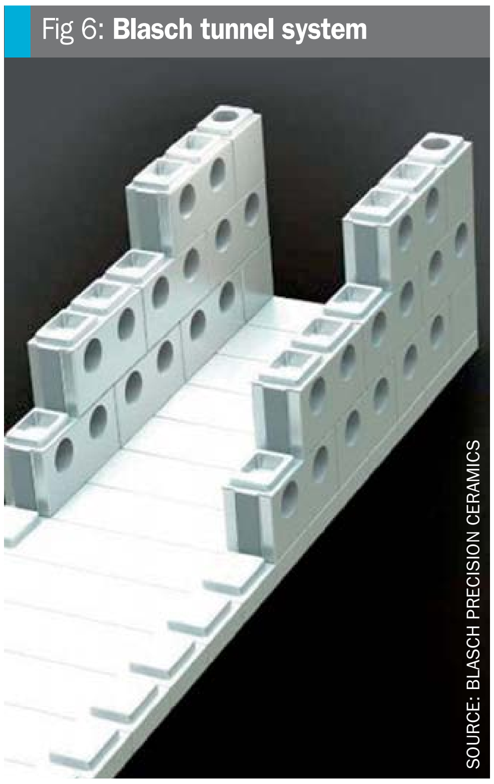
New Blasch StaBlox™ flue gas tunnel system

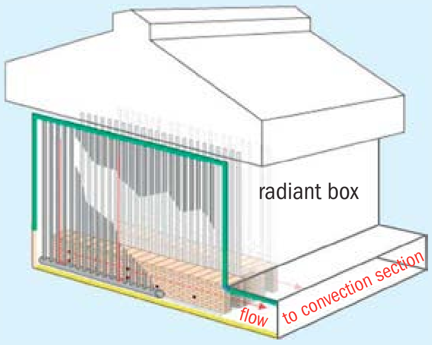
For decades, down-fired steam methane reformer furnaces have utilised flue gas tunnels (coffins) along the radiant section floor to collect and improve flue gas flow uniformity. These tunnels range from 1.2 to 3 m tall, 0.6 to 0.9 m wide, and 12.2 to 30.5 m long, depending on the unit design capacity. However, the conventional refractory firebrick or tongue-and-groove firebrick construction has always constrained the flue gas to non-uniform flow which has been correlated to non-uniform catalyst-tube temperatures and accelerated tube aging. Due to tunnel size and refractory volume, traditional brick design uses only basic shapes. Typical brick and mortar installations require several physical features including buttresses and large, periodic expansion joints which severely limit tunnel effectiveness, making uniform flue gas flow unachievable. The ability to design and construct tunnels using new highly-engineered refractory shapes, which eliminate these features, is new to this industry and could be the answer to improving flue gas tunnel effectiveness and improving catalyst tube reliability and longevity. In the July-August 2015 issue of *Nitrogen+Syngas* we featured an article by Blasch Precision Ceramics discussing how the reliability of primary reformer flue gas tunnels can be improved through the application of engineering design and improved material selection.

Fig 6: **Blasch tunnel system**



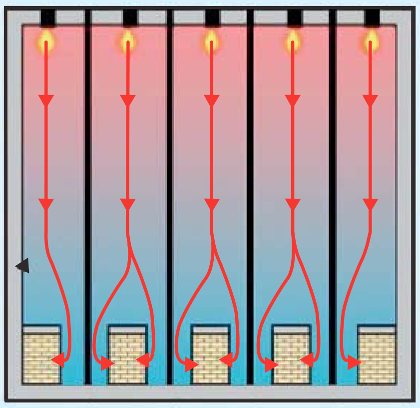
SOURCE: BLASCH PRECISION CERAMICS

Fig 7: **Radiant box flue gas flow**



Source: BD Energy Systems

Fig 8: **Flue gas flow into radiant box tunnels**



Source: BD Energy Systems

Utilising the StaBlox platform, BD Energy Systems developed a method for achieving near-perfect flue gas flow uniformity among and along the tunnels. This system combines BD Energy's vast steam methane reforming experience and Blasch's customised-precision-refractory-shapes design and manufacturing expertise. The result is unparalleled flue gas flow control using the patent-pending Blasch StaBlox™ flue gas tunnel system and BD Energy System's TOP Program. The new StaBlox™ reformer tunnel system can be used in furnace revamps or for new furnaces and can reduce installation time by 70-80% compared to conventional tunnel systems.

Conventional tunnel systems

Catalyst tube failure

Top-fired reformer arch burners heat catalyst-filled tubes for steam methane reforming. The catalyst tubes are heated by both radiation and convection from the flue gas (exhaust), which flows downward through the radiant box. Catalyst tubes typically are designed for a service life of 100,000 hours. In reality, however, tube longevity varies. Some tubes remain in service for 20 years, while others age much more rapidly, failing far ahead of schedule. Typically, reformers develop regions where tubes degrade more quickly, seemingly without cause. Catalyst tube inspection reports indicate that excessively high catalyst tube temperatures are correlated positively to accelerated catalyst tube aging and premature tube failure. Even when the average tube temperature is within design limits, non-uniform flue gas velocities cause some tubes to be heated more than others. Higher than average tube temperatures have been correlated to radiant box regions with greater than average flue gas velocities.

Flue gas flow

Hot flue gas flows from the arch burners into tunnels on the floor directly below each burner row. Flue gas enters the tunnel through tunnel wall openings distributed along the tunnel length and exits the open end of the tunnel to the convection section for additional heat recovery (Fig. 7). Ideally, radiant box flue gas flows vertically downward with uniform velocity throughout the box to achieve uniform catalyst tube heating and tube temperature and also to improve flame patterns. Consequently, the ideal total flow into each tunnel is proportional to the firing rate of their respective burner rows and the ideal flue gas flow rate into each tunnel is uniform along the length of that tunnel. Typically, burner outer-row firing is lower than inner-row firing because the outer row of burners must heat only one row of tubes, whereas inner rows heat tubes on either side of these burner rows. As a result, outer-row burners produce less flue gas than inner-row burners (Fig. 8). Therefore, proportionally less flue gas must be transported by the outer tunnels than by the inner tunnels. For example, if an outer burner row were designed to fire at 65% of the rate of an inner burner row, then the ideal outer tunnel flue gas load would be 65% of that of an inner tunnel. The ideal flow ratio between outer and inner tunnels is achieved by designing the outer tunnels with less tunnel-wall open-area and a smaller cross-section compared to inner tunnels. Uniform flow into a tunnel along the length of the tunnel requires less open area near the tunnel open end than near the tunnel closed end. Flue gas is drawn into the tunnel wall opening by the differential static pressure across the wall which is proportional to

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Fig 9: **Incremental flow per open-area column for conventional inner and outer tunnels**

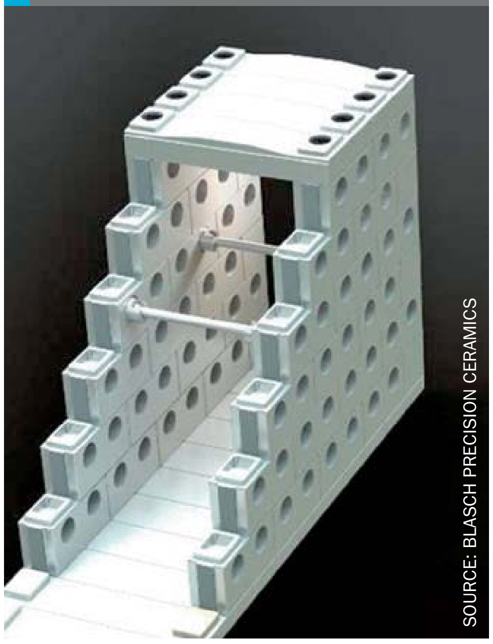
Source: BD Energy systems

the flue gas velocity inside the tunnel. Near the tunnel closed end where the in-tunnel flue gas velocity is very low the differential static pressure also is low, so more open area is required to draw in flue gas. Toward the tunnel open end, where the in tunnel flue gas flow rate and velocity is high, the differential static pressure also is high, so less open area is required to draw in flue gas. Ideal tunnel wall open area decreases gradually from the tunnel closed end to the tunnel open end. Due to certain physical constraints (see below), ideal open-area distribution is not achievable for the conventional tunnel system design.

Evaluation of conventional design

A conventional 12 m long tunnel system is evaluated (Fig. 9). Calculated total flow through each outer-tunnel is approximately 77% of the inner-tunnel flow, but this ratio is not constant along the tunnel length. For example, at each open-area column, the ratio of one outer-tunnel flow to one inner tunnel flow (the 'flow ratio') is calculated. The resulting average flow ratio is 77.4% +/-55.1%, with a standard deviation of 21.3%. Additionally, the 'high-flow' columns tend to be grouped together. For the 6 columns closest to the closed end, for example, the average outer-tunnel incremental flow is 110% that of the inner tunnels. For the 6 columns closest to the open end, however, the average outer-tunnel incremental flow is 56% that of the inner tunnels. Also, incremental flow is non-uniform along the length of each inner or outer tunnel. Following any open-area step change, the incremental flow increases with each successive open-area column. As in-tunnel velocity increases along the tunnel length, incremental flow through each successive column increases until an open-area-per column step-change reduces the open area and, consequently, the incremental flow. After the step change, incremental flow increases, again. The areas near buttresses and/or expansion joints are 'no flow' regions. Therefore, at the tunnel closed end, some flue gas generated above the inner tunnels moves laterally toward the outer tunnels and toward the radiant-box centre. At the tunnel open end, however, some flue gas generated above the outer tunnels moves laterally toward the inner tunnels and toward the middle of the outer tunnel. Half-way between the tunnel ends, flue gas generated above the outer tunnels moves toward the radiant-box center.

Fig 10: **Tunnel system with support tie rod**


SOURCE: BLASCH PRECISION CERAMICS

StaBlox™ interlocking tunnel system

Physical characteristics

The patent-pending StaBlox™ system utilizes five unique core tunnel construction components. The construction begins with a base component that spans the bottom of the tunnel and mates to the side wall blocks. The side wall blocks each contain two openings for conveyance of flue gas. These openings are readily field configurable for a variety of sizes facilitating even the most complicated flow balancing efforts. A tie rod system is employed if supplemental stability is required replacing the traditional buttresses that typically serve as a support structure (Fig. 10). These tie-rods easily can be removed and replaced during outages to allow easy access down the tunnel interior for inspection or repairs. At the top of the tunnel is a light weight lid that mates to the side walls. The sidewalls and lids each have provisions to seal against bypassing flue gas while accommodating differential thermal expansion of the overall structure.

Mass

Temperature differential stresses across a body can result in thermal shock failure. The most direct way to reduce the thermal stresses to below the refractory component yield strength is to decrease the refractory component wall thickness to allow the wall temperature to equilibrate more quickly and eliminate temperature differential stresses. The wall thickness should be as thin as possible without sacrificing the overall stability of the tunnel system. Because the tunnel system is self-supporting, component wall thickness reduction decreases the overall system weight. With the StaBlox™ design, tunnel system weight can be reduced by up to 60%. A light weight design coupled with a larger base component makes possible the use of highly insulating materials which would improve structural furnace support reliability and, therefore, improve overall system reliability. Material selection Selected materials for tunnel system components should have the highest creep resistance reasonably available, because a reduced creep will prolong tunnel system life and prevent premature failures. ASTM tests on super duty brick have published results of a 7.86% deflection at 1,427°C. An ideal candidate to replace super duty brick is mullite bonded alumina refractory material, which has published results of 1.11% deflection at 1,649°C.

In addition to creep resistance, a high HMOR (High Temperature Modulus of Rupture) also is critical for these tunnels. Comparing the same mullite bonded alumina to super duty fire brick results in a similar difference in material strength properties. Super duty brick has a <600 psi HMOR, high grade castable can have up to an almost 500 psi HMOR, and mullite bonded alumina has a 1700 psi HMOR. A fully characterised CTE (coefficient of thermal expansion), higher HMOR, and increased creep resistance will improve the overall tunnel system reliability.

Design technique

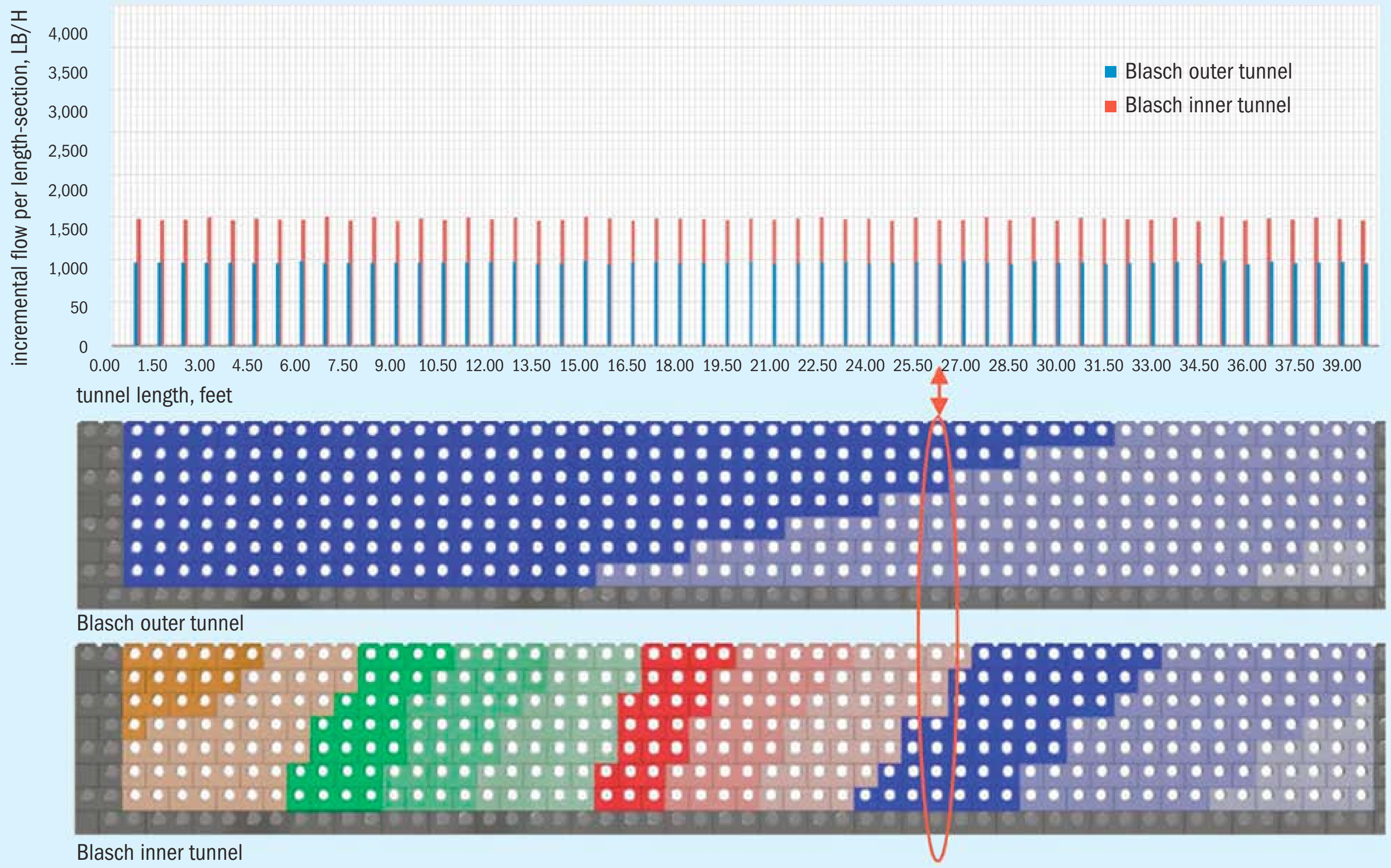
Open-area distribution design

The patent-pending StaBlox™ design method is to segment the tunnel length into half block sections, one column of openings per section. For example, a 23 m tunnel-wall length is segmented into 100 sections with openings in every course (row). Utilising BD Energy Systems' TOP Program, the open area is distributed along the tunnel length by specifying the orifice-insert internal diameter for each opening, rather than by specifying the per-section opening quantity (Fig. 11). Evaluation of BD Energy Systems' TOP Program The conventional tunnel system in Fig. 9 is redesigned using Blasch StaBlox technology in conjunction with BD Energy Systems' TOP Program. (Fig. 12). The goal is to achieve 65% flow through each outer tunnel compared to the flow through each inner tunnel and to achieve near uniform incremental flow along each tunnel length.

Fig 11: **StaBlox™ interlocking blocks with varied orifice insert diameters**

Source: Blasch Precision Ceramics

Fig 12: **Blasch tunnel evaluation**



Source: BD Energy systems

The inner and outer walls are segmented into 9 inch sections, one opening-column per section. Buttresses are not included and expansion gaps are evenly distributed among the blocks. Required open area per column is calculated and appropriate orifice insert diameters are selected for each opening. Each orifice size is illustrated with a unique colour. For each column, more than one orifice size may be specified, so the average orifice diameter per column gradually decreases closer to the tunnel open end. The outer tunnel requires very little orifice diameter change compared to the inner tunnel because the outer tunnel closed end flue gas velocity is very low. So, the outer-tunnel closed end acts somewhat like a manifold, whereas the inner-tunnel closed end develops high-velocity flow almost immediately. To be conservative, the minimum orifice-size step-change is arbitrarily specified well above manufacturing limitations. More finely tuned diameters are feasible. Calculated total flow through each outer-tunnel is approximately 65.64% of per-inner-tunnel flow, and this ratio is approximately constant along the tunnel length. At each open-area column, for example, the ratio of one outer-tunnel flow to one inner-tunnel flow (the ‘flow ratio’) is calculated. The resulting average flow ratio is 65.64% +/- 1.8%, with a standard deviation of 0.7%. Also, neither high-flow nor low-flow regions are grouped together. For the six columns closest to the closed end, for example, the average outer-tunnel incremental flow is 65.62% that of the inner tunnels. For the six columns closest to the open end, the average outer-tunnel incremental flow is 65.60% that of the inner tunnels.

Additional advantages

Reduced pressure drop

Because StaBlox™ tunnels do not require buttresses, the tunnel-wall footprint is narrower – typically half the conventional width. Therefore, the StaBlox™ interior tunnel-width can be increased without increasing the tunnel footprint. This increased interior width results in approximately one third greater cross-sectional flow area and significantly reduces pressure drop across the tunnel system.

Process flexibility

Often, operating conditions change after tunnel-system construction. A capacity increase may be desired, for example. Typically, in such cases, the existing tunnel-wall open-area distribution no longer performs optimally. For a conventional tunnel, open-area distribution redesign may require partial or complete reconstruction, incurring material costs and possibly lengthening the turnaround schedule. For a StaBlox™ tunnel system, however, open area redesign requires only the reconfiguring of the openings in each block impacted in situe (a relatively quick and inexpensive procedure), re-using the wall tunnel structure in its entirety. Reduced heat storage During heat up or cool down it is important to evenly heat or cool the catalyst tubes to avoid accelerated tube aging. However, the tunnels absorb heat during heat-up and release heat during cool down, causing non-uniform heating or cooling of individual tubes. During a trip, for example, while the catalyst-tube upper ends are cooling more quickly than normal, the tunnels radiate heat to the catalyst-tube lower ends. Because StaBlox™ tunnel mass is up to 60% less than conventional tunnel mass, StaBlox™ tunnels absorb and release 60% less heat, reducing the degree and period of uneven cooling. ■

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Deep vacuum fluid bed granulation

Ken Monstrey of Green Granulation Technology (GGT) shares the findings and experiences with regard to the commissioning and fine-tuning of the Linggu Chemical Phase II 2,700 t/d urea granulation plant in Yixing, Jiangsu, China.

Green Granulation Technology (GGT) Europe and the R&D department of GGT Asia have developed and commissioned a further enhancement of the cold recycle granulation (CRG) process. The CRG process has already been effectively adopted on industrial scale in several projects. The next generation of the CRG process, CRG under deep vacuum, has been successfully commissioned for three projects with capacities of 600 t/d,1,500 t/d and 2,700 t/d. In each of these projects the same principles of the CRG process were adopted, but then applied under the principles of deep vacuum.

Deep vacuum implies that the fluid bed granulator and the fluid bed cooler are operated at a negative pressure of approximately -500 mm WC, suggesting a pulling force rather than a pushing force on the airflow through the system.

Linggu Phase II

With the completion of the Phase II project, Linggu Chemical, located in Yixing, Jiangsu, China, now produces 2,800 t/d ammonia, 2000 t/d urea prills and 2,700 t/d urea granules.

The Phase II project comprised a 1,500 t/d ammonia plant by KBR, 2,700 t/d urea synthesis by Stamicarbon (pool condenser technology) and 2,700 t/d CRG deep vacuum urea granulation by GGT. Full commissioning was carried out in 2015.

The urea granulation plant was designed with two exhaust fans linked to the GGT “double temperature” scrubbing technology. A small, dedicated fluidisation air fan was provided for the chilled compartment of the fluid bed cooler and a relatively small main fluidisation air fan, which only requires the capacity to deliver 300 mm WC pressure. This main fluidisation air fan can be shut down and completely excluded from the system by opening the inlet hatches on the fluidisation air collector.

With or without the main fluidisation air fan, the system is operated under a vacuum of approximately -500 mm WC in the upper casings of granulator and cooler. The main fluidisation air fan can be activated for periods when extra airflow is desired.

The main advantages of the deep vacuum technology can be found in the better evaporation of water in the spray area inside the fluidised bed and in the fact that through bypassing the main fluidisation air fan, the heat generated by this fan is eliminated. This means that for the same amount of fluidisation air, more effective cooling is realised by the fluid bed cooler and less air is required in the granulator as a vehicle to remove heat from the bed. Consequently there are also savings in electric power consumption.

For this technology to be economically feasible and beneficial, certain conditions must be met. For example it is important to reduce the pressure drop over the system as much as possible so that the exhaust fan(s) can be limited in size and power. Practically, GGT realises this by minimising the pressure drop over the fluid bed by operating at a low bed level of approximately 450 mm, both in the granulator as in the fluid bed cooler. This is made possible by the “optimised dynamics” principle in the fluidised bed, which refers to a patented technology that embodies the arrangement of the air-assisted urea spray nozzles in such a way that banks of open spaces are formed between the rows of sprayers to enable a rolling motion inside the fluidised bed layer. Furthermore, GGT applies its “double temperature” scrubbing technology that uses BlueFil® demister pads that generate hardly any pressure drop. This solution combines high performance air treatment with very low total pressure drop.

This combination of essential factors makes it possible and beneficial to realise the deep vacuum technology in an industrial environment.

The data collected from the Linggu start-up and fine-tuning have confirmed that the GGT urea distribution system, combined with the low effective atomisation air pressure and flow on the air nozzle that the GGT sprayer requires, is resulting in a recycle back to the urea synthesis as low as 2,5%, calculated on end-product capacity. This provides important relief for the urea synthesis plant without any compromise on product quality or plant reliability. Linggu Chemical’s order book is completely filled and all of its granular urea production is exclusively intended for the export market.

The GGT deep vacuum process can, given minor adjustments, be made suitable for applications other than the production of pure nitrogen based granules. It can also be adapted to enable production of urea enriched with ammonium sulphate or urea with sulphur addition. Sulphur and ammonium sulphate are often byproducts of other industrial processes and are of lower economic value, although they can prove to be of great importance for well-balanced fertilisation of the soil. ■

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Lessons learned from ammonia industry incidents

Clariant reports on two catalyst related incidents in ammonia plants and reviews the lessons learned. The first incident relates to LTS catalyst reduction and a primary reforming coking event and discusses the troubleshooting that was completed. The second incident describes the metallurgical and catalyst effects of air being inadvertently introduced into an HTS reactor with reduced catalyst.

Ammonia plant incident 1

Ammonia plant no. 1 (USA) was built by MW Kellogg and commissioned in 1968 with a nameplate capacity of 907 t/d and has been modified in several stages to its current capacity of over 1,361 t/d.

The facility had a routine turnaround planned for the summer of 2014 to perform scheduled maintenance, conduct required inspections, and replace catalysts. During this shutdown, the plant replaced catalysts in the desulphurisation system, high temperature shift (HTS) reactor and low temperature shift (LTS) main reactor. The LTS catalyst required a reduction step before being placed into service. The plant did not replace the catalyst in the primary reformer, which had been in service for three years.

During the turnaround, a plant incident during the LTS reduction caused the pressure drop across the primary reformer to triple. The plant start-up team and Clariant Technical Services worked together to determine the cause of the primary reformer pressure drop increase and implement procedures to attempt salvaging the charge of reforming catalyst.

LTS reduction safety considerations

LTS catalyst is installed in the oxide form and requires a reduction at elevated temperatures and in the presence of a controlled amount of hydrogen to provide active copper crystals.

There have been numerous incidents in the past where hydrogen leaks in the system have caused LTS catalyst beds to reach temperatures above 870°C, which is greater than the temperature ratings for most LTS catalyst vessels. If the catalyst bed temperature is allowed to exceed 230°C, natural gas present during the reduction can crack, causing more hydrogen formation and a runaway temperature event.

To prevent overheating due to hydrogen leaks, good operating practices include the following:

- blinding off known hydrogen sources from the carrier gas loop;
- calibrating the hydrogen control valve at low temperatures to confirm the hydrogen concentration going to the LTS reactor;
- monitoring the inlet and outlet hydrogen content for the LTS reactor frequently;
- monitoring the thermocouples present in the LTS bed continuously.

Closely monitoring these data points reduces the risk of damaging the LTS catalyst (which accounts for more than 30% of a typical ammonia plant's total catalyst cost) and prevent having to replace the catalyst vessel.

Plant start-up and LTS reduction

Clariant's customer began restarting the ammonia plant on August 30, 2014. Due to the configuration of the LTS guard beds and the LTS main bed, the plant was able to begin ammonia production before the reduction process began for the LTS main reactor catalyst.

The LTS main bed reduction began on September 4, 2014. The reduction process was interrupted multiple times and was not completed until September 29, 2014.

The reduction was initially interrupted by a process upset and trip, which triggered a mechanical failure in the process air compressor train. The process air compressor repairs led to a full shutdown of the ammonia plant, which stopped the LTS reduction.

After the process air compressor was repaired and while trying to finish the reduction, plant and Clariant engineers determined that synthesis gas was leaking into the reduction loop, and that the source was inadequate isolation from the LTS guard beds, which were in service. Clariant's gas chromatograph indicated 0.5 mol-% hydrogen flow leaking into the beds. The plant start-up team and Clariant discussed how to remove the hydrogen or control the hydrogen leak. Since this hydrogen ingress could not be controlled, Clariant recommended installing a blind to prevent hydrogen from the guard beds entering the reduction loop. The plant was removing the reduction carrier gas when a process trip occurred due to high air to gas ratio, leading to a full plant shutdown. When the plant tried to restart, the pressure drop across the reformer had more than tripled.

Plant and Clariant engineers quickly switched from supervising the LTS reduction to troubleshooting and determining

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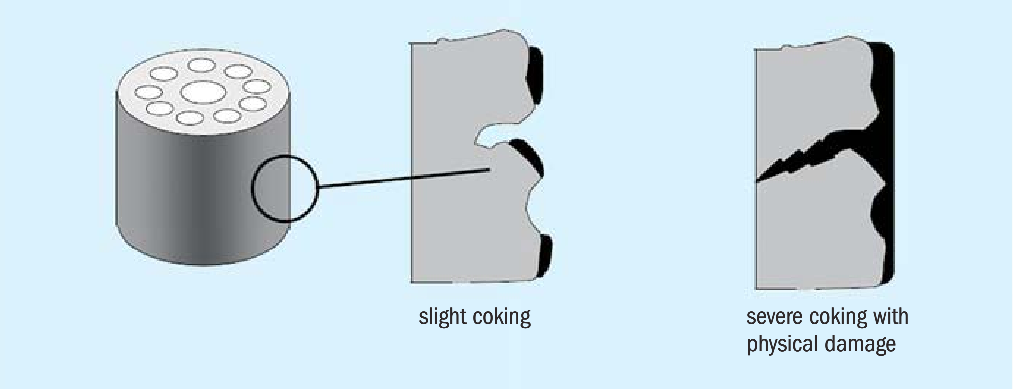
Fig 1: **Reforming catalyst coking and physical integrity**



the root cause of the primary reformer pressure drop issue

Troubleshooting

After the plant trip on September 15, 2014, the ammonia plant was in the process of restarting the ammonia plant, but experienced difficulties introducing process steam to the primary reformer. The steam flow into the catalyst tubes was severely restricted, with a very high pressure drop indicated across the primary reforming catalyst tubes. After several unsuccessful attempts to introduce the steam to the reformer, the plant engineers and Clariant suspected that coke may have been formed on the reforming catalyst during the shut-down event. Observation of the radiant section showed that over 50% of the tubes were bright red indicating low or no flow through them. As the pressure drop increases in some of the tubes of the reformer, a flow imbalance occurs in the reformer causing some tubes with low flow to be operated at higher than design temperatures, which could lead to a reduction of tube life. Conversely, the tubes with high flow rate have lower temperatures. The pressure differential on the primary reformer was 896 kPa, while the normal pressure drop was 240-280 kPa. At this point, the decision was made to start a catalyst decoking procedure.

Primary reformer pressure drop increases are normally caused by physical degradation of the catalyst and/or coking of the catalyst.

During unplanned plant shutdowns, there is a rapid contraction of the reformer tubes causing a significant amount of physical stress on the primary reformer catalyst. If the stress is too large, the catalyst will physically crack leading to dust and catalyst chips obstructing the process gas flow through the catalyst. The pressure drop across the reformer increases due to the physical impediments in the tubes. For this reason, high crush strength is a key parameter for catalyst selection.

At low steam to carbon ratios, coke will form on the catalyst. This will occur both on the surface and in the pores of the catalyst. The carbon will expand at high temperatures which can also cause a loss of physical integrity of the catalyst (see Fig. 1). Depending on the severity of the coking event, coked up catalyst can potentially be reactivated through decoking procedures.

Clariant's catalyst decoking procedure with steam was implemented. The first step was to ensure natural gas flow to the reformer was shut off. The steam flow was then introduced at 50% of design rate at atmospheric pressure. The reformer firing was adjusted to maintain an exit temperature of 704-760°C, while maintaining the tube wall temperatures below the maximum design limit. The steam decoking process was allowed to continue for 24 hours.

After steaming the reformer for 24 hours, there was no significant change in the primary reformer pressure drop. After consulting with Clariant and other catalyst suppliers, the decision was made to attempt to remove the coke formation by using an air-steam decoking procedure.

The air-steam decoking process is a last resort for trying to salvage severely coked catalyst prior to replacement. This procedure is similar to the steam decoking method mentioned earlier, but air is added to the process steam to introduce a maximum of 1% oxygen in the reformer steam feed. The tube wall temperature and exit temperatures should be monitored to keep them within normal ranges. This procedure can be attempted for 12-36 hours.

The key control point for the air-steam decoking process is controlling the total amount of air going to the reformer to avoid further damage to the catalyst or tubes due to overheating. Clariant recommended venting the air-steam mixture directly after the primary reformer, but with the MW Kellogg reformer configuration it is impossible to isolate the secondary reformer from the decoking process. A blind was installed at the HTS inlet and air-steam flow was routed to the vent upstream of the HTS vessel. The secondary reformer temperatures were monitored very closely to prevent extreme exotherms.

The air-steam decoking began with the steam introduction; then air was slowly added at 0.1%. Through-out the process, air was increased up to 5% (~1% O_2). Hourly steam condensate samples were collected from the inlet and outlet of the Reformer and the pH was measured to check the decoking progress. Carbon dioxide forms when carbon is reacted with oxygen during the decoking process. The carbon dioxide will be adsorbed in the steam condensate in the reformer causing the pH of the steam condensate to drop. Monitoring the pH of the inlet and outlet steam condensate is a simplified way to monitor the amount of carbon removed from the catalyst during the decoking process.

The air-steam decoking was continued for 12 hours, but there was only slight reduction in the pressure drop, making the operation of the unit impossible. At this point, the plant management decided to end the decoking process and replace the catalyst.

The primary reformer catalyst was replaced with Clariant's ReforMax® 210 LDP and 330 LDP catalysts. Clariant provided two engineers to supervise the unloading and loading of the catalyst. The unloading process was longer than normal due to the physical degradation of the coked catalyst. The catalyst tubes also had to be cleaned out before loading the new catalyst charge. The primary reformer loading was successfully completed with all but three of the tubes within ±5% pressure drop variance.

Root cause analysis and lessons learned

This incident began when the carrier gas flow used for LTS reduction was suddenly stopped resulting in the process air trip (due to high air to gas ratio). This trip began a cascade of events which led to a loss of steam and a full plant shutdown. The primary reformer catalyst was finally damaged by coking as it was exposed to natural gas without steam for approximately 30 minutes as a consequence of leaky shutdown valves.

The carrier gas flow was stopped due to synthesis gas leaking into the LTS

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Fig 2: **Plant no. 1 process gas configuration**

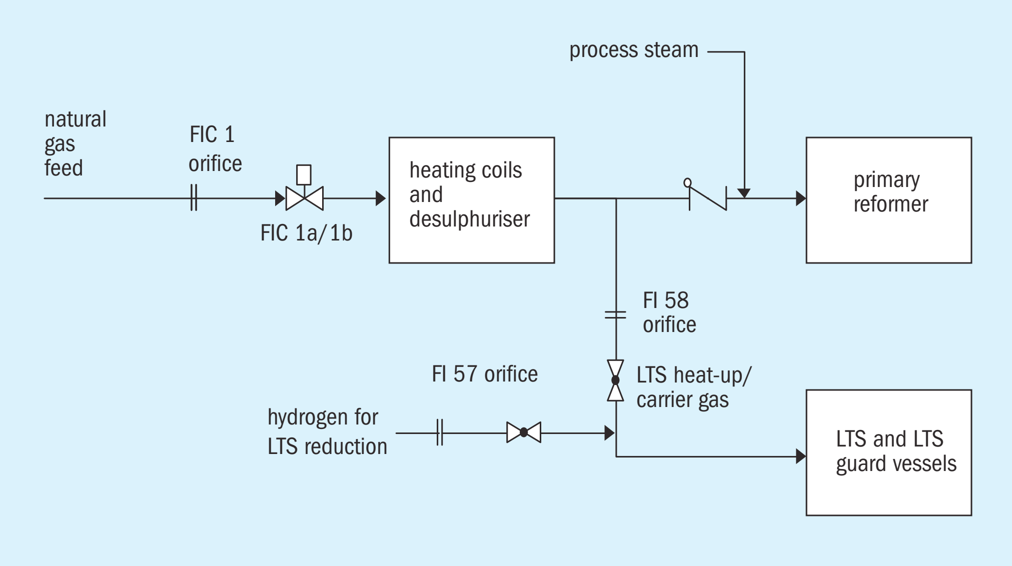
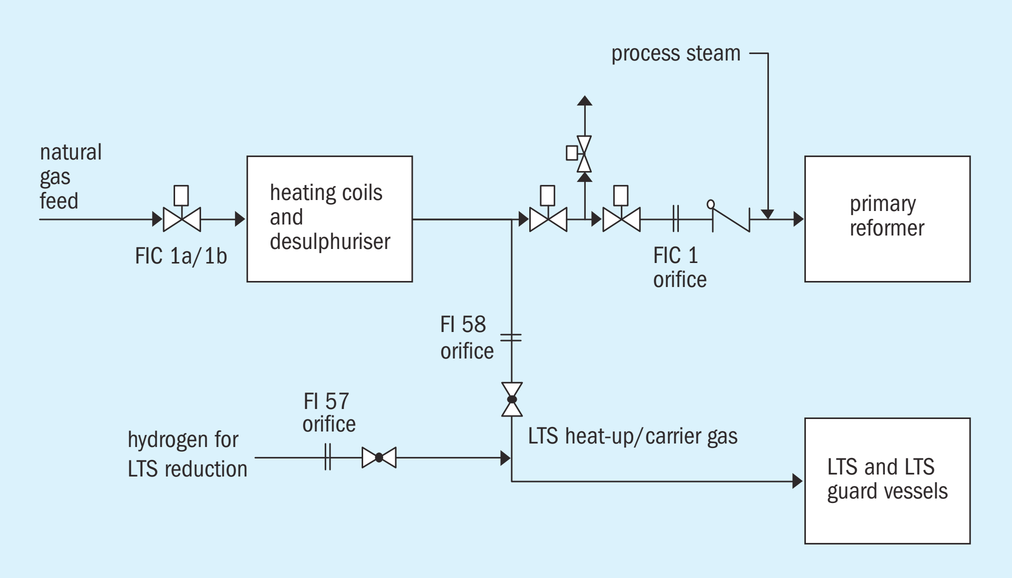


Fig 3: **Plant no. 1 planned process gas configuration**



reduction loop. This could have been avoided by installing isolation blinds at all potential leakage points during a LTS catalyst reduction.

The location of the process gas flow orifice also contributed to the failure (Fig. 2). Since the orifice is upstream of the carrier gas branch the ratios calculated for the process air and gas trips were inaccurate. This flow element will be relocated to downstream of the carrier gas branch to eliminate this issue.

The use of the flow control valves as shutdown valves was also a contributing factor. It was discovered that the control valves were Class IV leakage rated. These valves were replaced with Class V leakage rated valves. Also, as a temporary measure, a motor operator was installed on the block valve upstream of the process gas control valves. On process gas trips, the flow control valves will close, and the upstream block valves will be closed by the motor operator.

As a permanent solution, dedicated shut-off valves (in a double block and bleed arrangement) will be installed, with a dedicated flow measurement element (Fig. 3).

Current performance

After the primary reformer loading was completed, the LTS main bed catalyst was successfully reduced and put on-stream. After the turnaround, the catalysts were both performing well. The pressure drop across the primary reformer was reduced by 26% from end-of-run to start-of-run.

The LTS main bed performance also improved greatly from 0.22 mol-% CO slip to 0.11 mol-% CO slip with Clariant ShiftMax® 217 installed.

Clariant and the plant expect both the primary reformer and low temperature shift catalyst to enjoy long lives.

Ammonia plant incident 2

The initial start-up and reduction of the high temperature shift (HTS) catalyst is a procedure which is performed relatively infrequently in ammonia plants. This procedure allows for a safe, controlled reduction of the HTS catalyst primarily by operating at a high S/G ratio at the primary reformer. A proper initial startup is important to ensure that the catalyst is able to achieve maximum CO conversion combined with a long on-stream life. While many ammonia plants (including the large ammonia plant no. 2 also located in the USA) have performed HTS startups with no problems, events can occur that can lead to poor catalyst performance, reduced HTS reactor efficiency, and more serious issues including loss of vessel integrity.

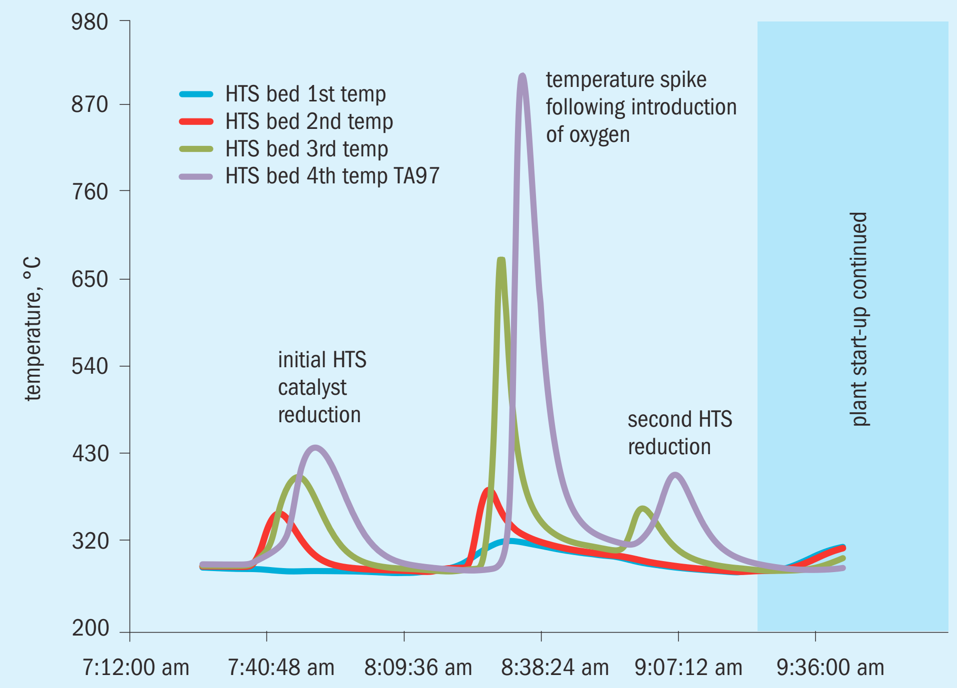
The large ammonia plant no. 2 (USA) was designed by MW Kellogg with a nameplate capacity of 1,000 t/d. Following revamping the plant now has a capacity close to 1,500 t/d.

In October 2010, a new catalyst charge of ShiftMax® 120 HTS catalyst was installed. The catalyst reduction was deemed a success and the plant came up to normal operating rates. However, the first detailed analysis of catalyst performance after startup showed that the HTS catalyst CO conversion was less than expected. The reactor was leaking over 3 mol-% CO compared to an expected 2-2.5% (based on historical performance and experience with the catalyst).

Clariant, as catalyst provider, worked with the plant site to provide guidance and troubleshooting efforts and then reviewed the initial catalyst reduction data. The reduction was performed by the plant's operations team and both parties agreed that it was a "textbook" reduction with no issues. However, based on the temperature profile from the reduction and current operation, it was found that TI-9, which previously showed exotherm during the reduction, was not showing exotherm during operation. This pointed to a possible screen failure, or some kind of settling event which would cause the bed to shrink. TI-9 was located at a depth of 4.6 m. However, there was no identified pressure drop increase across the reactor. At the time, this one piece of information was not conclusive and did not point to a known incident which could have affected performance.

Clariant recommended temperature increases to try and improve CO conversion. These steps were undertaken by

Fig 4: **HTS bed temperatures**



Data collected by plant no. 2 (USA)

the plant but did not improve the catalyst performance.

In December 2011, it was decided to bring the plant down to repair other process equipment. During this short outage, it was also decided to change the HTS catalyst due to the high CO leakage of the HTS reactor. Clariant personnel were on-site to supervise the unloading process to help troubleshoot the cause of the poor performance.

Upon observations from unloading of the catalyst and additional review of process data, it was determined that shortly after the initial catalyst reduction in October 2010, air was inadvertently introduced into the secondary reformer which reached the reduced catalyst in the HTS reactor, causing a major high temperature event in the bottom of the vessel.

Incident root cause analysis

The root cause of the high temperature event was determined to be introduction of oxygen to the HTS resulting in rapid oxidation of the catalyst and a significant elevation in vessel temperature. The oxygen was introduced when compressed process air pressure exceeded process gas pressure impeding process gas flow to the HTS. Historically, this balance between process gas and air pressures was maintained using a manually operated vent that allows the elimination of excess air pressure during plant start-up. However, due to process control modifications made during turnaround, the lack of process gas flow was not recognised.

Several process-control modifications were made during turnaround including implementation of a new safety-instrumented system and the elimination of a two-step low-flow trip that was historically used during start-up. The functionality of the two-step low-flow trip was removed, but the switch remained in place on the board causing additional confusion during start-up. This was identified as a contributing factor in the root cause analysis.

The HTS bed temperature profile during the initial catalyst reduction, high temperature event, and secondary catalyst reduction are shown in Fig. 4. As illustrated, the rapid increase in HTS temperature decreased back to 316°C within 25 minutes and went unnoticed. Following the secondary catalyst reduction, plant start-up was completed without further issue. The catalyst performance issue was identified later during post-start-up analysis of HTS CO conversion. There were no pressure drop problems even after the high temperature sintering of the catalyst and shrinkage of a portion of the bed to tablets of approximately 50% of their original size.

Lessons learned

To address the potential for high temperature hydrogen attack (HTHA) of the HTS vessel, plant personnel elected to upgrade the vessel's metallurgy to a 1.25% chromium 0.5% molybdenum steel alloy material. This material was selected based on data presented to API by Mr. G.A. Nelson in 1949 (aka, "Nelson Curve"). The Nelson Curve depicts the temperatures and pressures at which certain steel materials will begin to show signs of internal and surface decarburisation and is updated as new data become available. The trend for the material selected indicates a higher resistance to HTHA than the original carbon steel material.

Additionally, two operational changes were made to reduce the likelihood of introduction of oxygen to the HTS during start up.

The first included a modification of the plant start-up procedure to minimise the possibility of introducing oxygen to the HTS. The plant is equipped with a low process gas flow trip that recirculates the air compressor (i.e., stops the process air flow into the plant) upon loss of process gas flow. However, the previous plant start-up procedure required temporary modification of this trip until adequate flows of both process gas and process air could be established. The revised start-up procedure requires that the process gas flow rate be increased to a level at which introduction of oxygen to the HTS is highly unlikely prior to starting the process air compressor.

This change increased the quantity of process gas (i.e., natural gas) utilised for start-up but provides adequate protection of the HTS. As a second level of protection, a process air to process gas ratio (flow based) trip was installed that will also recirculate the process air compressor if the ratio exceeds the trip set point.

The combination of the metallurgy upgrade, start-up procedure revision, and installation of the air:gas ratio trip provides for the safe start-up and operation of the HTS. ■

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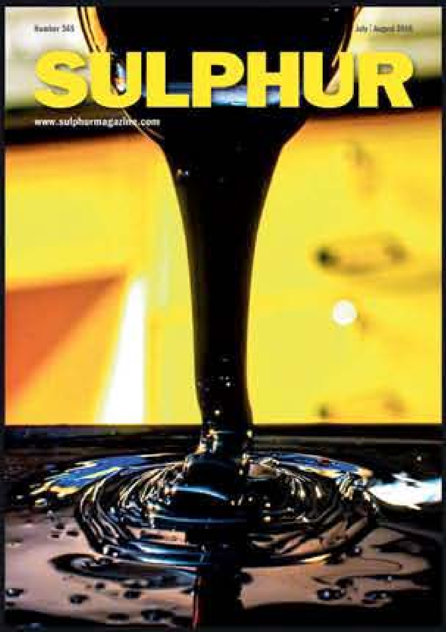
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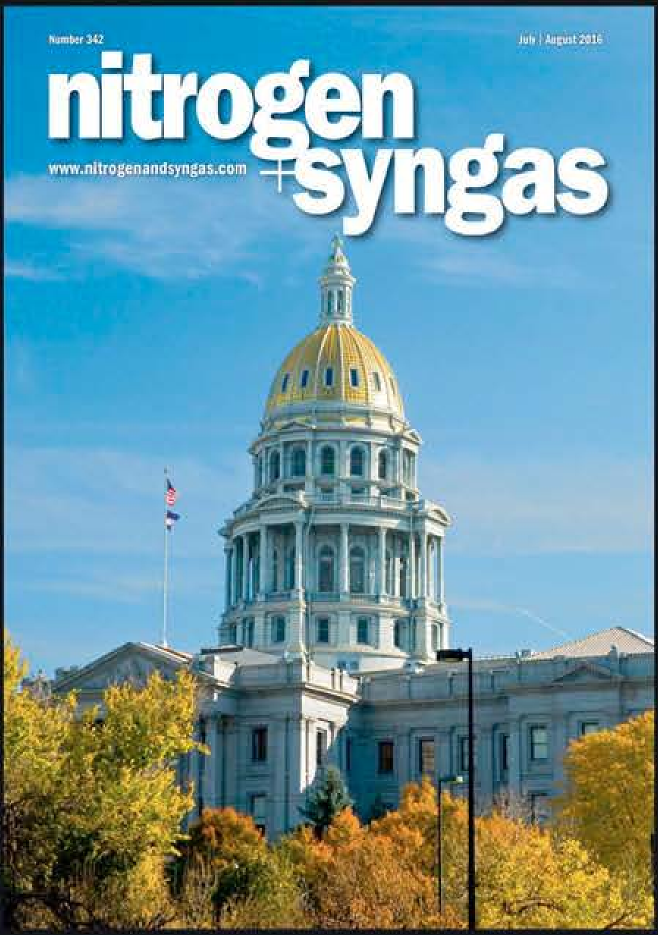
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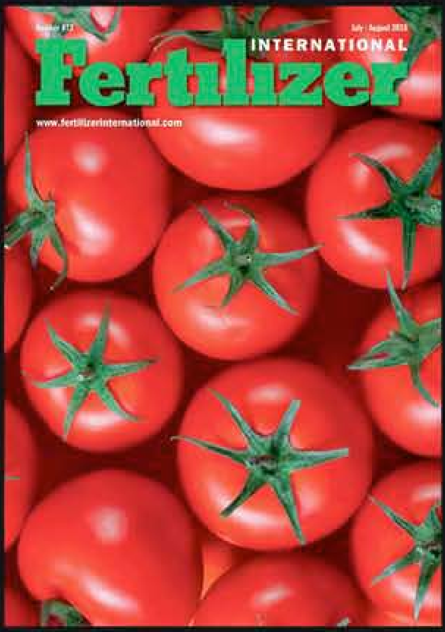
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